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The biology and ecology of Dendroctonus valens Lec., and the biology, ecology, and control of Dendroctonus frontalis (= mexicanus) Zimm. in central Mexico (Coleptera: Scolytidae).

William Edwin Rose
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THE BIOLOGY AND ECOLOGY OF DENDROCTONUS VALENS LEC.; AND THE BIOLOGY, ECOLOGY, AND CONTROL OF DENDROCTONUS FRONTALIS (= MEXICANUS) ZIMM. IN CENTRAL MEXICO (COLEOPTERA: SCOLYTIDAE).

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A Dissertation Presented

By

WILLIAM EDWIN ROSE

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S E C T I O N I

THE BIOLOGY AND ECOLOGY OF THE RED TURPENTINE BEETLE *Dendroctonus valens* Lec. IN CENTRAL MEXICO (Coleoptera:Scolytidae).

Introduction

The genus Dendroctonus (means killers of trees) has caused more destruction and mortality to forest trees in the United States and Mexico than any other genus of the family Scolytidae, members of which are commonly called bark beetles. The Scolytidae causes an estimated 90% of the insect produced tree mortality in the United States forests (Anderson,1960). In Mexico species of Dendroctonus are responsible for more than 80% of the destruction of forest trees by insects (Hartig,1954).

The first recorded observation of an epizootic by Dendroctonus beetles in Mexico was by Bonansea in 1903 (Perry,1951). No doubt earlier epizootics occurred for many centuries prior to this date. Probably, only epizootics of several trees or more were recorded since low populations are inconspicuous and usually not observed.

The pine forests of Mexico have repeatedly suffered from epizootics of several species of Dendroctonus beetles. Probably the most important, and primary pest, is Dendroctonus frontalis Zimm. In Central Mexico Dendroctonus valens Lec. is a secondary pest attacking the base of the trees, usually following an attack by Dendroctonus frontalis.

Little research has been done on Dendroctonus valens, commonly known as the Red Turpentine Beetle. The need for information on this pest, especially under Mexican environmental conditions, stimulated this

investigation of its biology and ecology under laboratory and field conditions. The emphasis in the laboratory study was on the response and development under different temperatures. The emphasis in the field research was on observations of the beetles attack habits, evidence of attack, and in recording existing temperatures in the beetle's niche under the bark during the warmest and the coldest seasons of the year.

Analysis of Literature

Economic importance. Dendroctonus valens is not economically important in Canada, the United States, and Mexico except upon shade trees along roads, in parks, and near homes (Smith,1961;[1]). The beetles are usually secondary pests attacking the trees after biotic and abiotic factors have weakened and partially killed them. In many regions it is considered only as a destroyer of stumps.[1] In the state of Chihuahua, Mexico, the beetle has been reported as a primary pest of small pine trees ranging from 3-10 cm stump diameter. At these diameters, a primary attack by one family (one male and one female) in a single oviposition gallery will eventually kill the small tree.[2,3,4] In Central Mexico it has been observed to attack trees, usually without success, which have been opened or wounded for the collection of resin, or resin-soaked wood for fuel. Trees damaged by fire are also attacked.

Smith (1961) stated that the beetle usually attacks pole-size or larger trees that exhibit reduced vigor or have been attacked by other bark beetles, but it will, under certain conditions, attack trees that are apparently healthy. It is often destructive in areas disturbed by fire, logging, and land clearing. Injured trees, and trees adjacent to freshly cut lumber are also attacked. Three per cent of residual trees left for seed production have been attacked after logging. These residual trees near logged areas were probably attacked because of the high population that developed in the stumps left over from logging (Rudinsky, 1962). Rudinsky also mentioned that other attacks on healthy trees growing near freshly logged and piled lumber probably result from concentration of beetles that are attracted by the odor of turpentine.

Distribution. The distribution of D. valens is in the coniferous forests of North America, except for Florida, north of Guatemala and Honduras (Wood,1963;5).

Smith (1961) notes that the range is very similar to the distribution of Pinus ponderosa in the West and Pinus strobus in the eastern part of North America. A very closely related species, D. terebrans (Oliver) replaces D. valens in southeastern United States and is often confused with the latter where the range overlaps.

Chamberlin (1939) reported the same wide range with the genus restricted to the North American Continent.

D. valens has the widest distribution of the genus. A large variety of host trees exists throughout its range. D. valens lives below 3000 meters in Central Mexico,[5] and between 3000 and 1500 meters in Guatemala (Schwerdtfeger and Becker,1955). Temperature, as determined by altitude, probably plays an important role in the distribution.

Host trees. The host trees are numerous and include the genera Pinus, Picea, Pseudotsuga; Abies, and Larix. These are as follows: Pinus arizonica Engelm., ayacuahuite Ehr., Chihuahuana Engelm., contorta Dougl., coulteri D. Don., echinata Mill., edulis Engelm., jeffreyi Grev. & Balf., lambertiana Dougl., lawsoni Roezl., leiophylla Schol. & Cham., montezumae Lamb., monticola Dougl., murrayana Balf., oocarpa Schiede, patula Schl. & Cham., ponderosa Laws., pseudostrobus Lindl., radiata D. Don., resinosa Ait., rigida Mill., rudis Endl., sabiniana Dougl., sylvestris L., strobiformis, strobus L., tenuifolia Benth., and virginiana Mill.; Pseudotsuga menziesii (Mirb.) Franco; Abies concolor (Gord. & Glend.) Hoopes; Larix laricina (DuRoi) K. Koch; Picea glauca (Moench.) Voss., abies (L.) Karst, and rubens Sarg. (Schwerdtfeger and Becker, 1955; Wood, 1963;[6]).

In Central Mexico only Pinus sp. were observed to be attacked, even though other species of Abies and Picea were at higher elevations in the same area.[5] The species most commonly attacked in Central Mexico was Pinus leiophylla.[5]

Taxonomic position. The genus Dendroctonus as originally described by Erichson (1836) included five

species. Hopkins (1909b) and Wood (1963) have revised the genus. D. valens was described by LeConte in 1868.

Wood (1963) stated that the genus Dendroctonus is not closely related to any other genus of Scolytidae, but is distantly related to genera of other continents such as Hylurgonotus Schedl of South America. D. valens is the largest species in the genus and is very closely related to D. terebrans. Mature adults of D. valens are readily distinguished from D. terebrans by the reddish brown body color (D. terebrans is black), the smaller punctures in the lateral areas of the pronotum, the smaller, less abundant declivital granules, and in part, by geographic distribution (Wood,1963).

Wood (1963) reported that, "Specimens from the northeastern parts of the range appear to be somewhat smaller than those from other areas; however, this may result from the limited material at hand, rather than actual population difference. The sexual differences in the frons appear to be more strongly developed in series originating in southern Mexico and Guatemala. There is also a tendency for the egg galleries of some specimens from those areas (the latter) to be elongate and narrow; however, neither the sexual nor the gallery character is found in a majority of the population in those areas."

Association of species. D. valens and D. frontalis were usually located in the same areas attacking the same

trees in Central Mexico. D. frontalis was the primary insect, while D. valens attacked the trees after D. frontalis or other species of bark beetle or other insects or agencies have weakened them. D. valens usually attacks within one meter of the ground line or more commonly, at the ground line, and the parental gallery extends toward or into the roots. D. frontalis first attacks the middle trunk with later attacks extending upward into the crown and downward to the ground line. Both of these insects carry fungi which seemingly lead to earlier death of the trees and help initiate wood decay. D. valens, outside the range of D. frontalis, is associated with bark beetles of other genera.[6]

Schwerdtfeger and Becker (1955) reported that D. valens was a primary insect on healthy trees in Guatemala. In Mexico, when the primary bark beetle, D. frontalis, declines and does not prepare additional susceptible trees, the secondary bark beetle, D. valens, also declines.[6] However, in the state of Chihuahua, D. valens was a primary insect attacking and killing small pine trees not previously weakened by other bark beetles.[2,4]

Wood (1963), stated that D. valens is generally a secondary enemy of pine and spruce, usually following attacks of more aggressive bark beetle species.

General description of the stages. The adult is cylindrical,[8] from 5.7-10.0 mm long and light to dark red in color. The pronotum is broad, coarsely punctured, with

sides narrowing towards the head, but constricted. The eggs are oblong to oval, opaque white, and a little over 1 mm long. The larvae are legless, grublike, and vary from 1-12 mm during development. The larval head capsule is clear white after moulting and changes to orange, then to orange red, red, and reddish brown during east instar. The pupae are about 9 mm in length and milky-white in color. The callow adults are whitish, light colored, changing to orange, orange-brown, reddish brown or dark reddish brown upon reaching maturity (Fig. 7), (Hopkins,1909a, 1909b; Smith,1961;[6]).

Wood (1963) described the adult types as follows: "Male length 5.4-9.0 mm (average about 8), 2.3 times as long as wide, mature body color reddish brown. Female similar to male except a median frontal elevation evident at upper level of eyes; pronotal punctures very slightly larger; and discal crenulations and declivital granules a little larger."

Schwerdtfeger and Becker (1955) described the adult and larvae from their work in Guatemala as follows: "D. valens is distinguished by its size from other species of the genus in Guatemala: the beetle measures from 6-10 mm long, ordinarily 8-9 mm and has a body color clear to dark and always a reddish brown in color; head wide without inflection in the front; prothorax wide and roughly punctured, smoother towards the head; elytra with sutures

transversal and oblique, between rows or punctures more less clear; the body is sparsely covered with long hairs without order of distribution.

"The larvae may develop to 12 mm in length. The last abdominal segment has dorsal plates with six strong spines."

Biology. Hopkins (1909a) described the life history in detail. He stated that there is usually one generation a year in the United States but in warmer locations the possibility of a partial second generation exists. He also stated that a generation may require 2-3 years. DeLeon (1942) reported that all stages are present throughout the year, the number of generations varies from one in temperate zones to two in warmer regions, and in colder northern regions it may take two years to complete a generation. All stages, including the egg, were observed throughout the year in Central Mexico.[6]

The adult female reaches the host tree first and bores through the outer and inner bark to the cambium layer. The xylem surface is also etched. The male enters the gallery shortly after the female. After reaching the cambium region the female bores upward at first and continues enlarging the gallery laterally or vertically until sap flow has stopped. Once sap flow has stopped the female bores downward toward and usually into the roots (Fig. 7,8), (Smith,1961; Wood,1963;[6]).

There are no egg niches and the white, oval eggs are laid in elongate masses or groups of 10 to 40 in the gallery. The gallery is usually wider, 4-15 mm in areas of oviposition. Elsewhere the gallery is 4-6 mm wide. The eggs may have frass and waste borings packed around them. This gallery construction and egg laying habit are characteristic only of D. valens and D. terebrans within the genus (Smith, 1961; Wood,1963;[5,6]). Wood stated that oviposition and brood activity usually occurs between May and October in the northern parts of its range and throughout the year in the southern areas. In Central Mexico, oviposition was observed throughout the year.[6]

The incubation period of the eggs varies from 10-14 days (Smith,1961; Wood,1963). Once hatching occurs, the larvae feed side by side making a fan shaped gallery as they develop. The gallery is formed between the bark and wood. The gregarious larvae feed upon the cambium and the inner phloem bark cells. They feed in a lateral direction away from the vertical adult gallery and can extend the larval galleries from a few inches to more than a foot in width. The gallery behind the larvae is filled with reddish frass. The larvae complete their development in about two months, but in northern latitudes it may be extended to a year or more (DeLeon,1942; Smith,1961; Wood,1963). When the larvae reach full growth they make separate pupal cells along the outer margin of the larval gallery. After the cells are

formed in the inner phloem from frass and bits of wood, the insects go into a quiescent prepupal stage and within a day transform to the pupal stage. Occasional larvae make short individual galleries beyond the main gallery to construct the pupal cell. During larval development the adults usually continue to feed and extend the main gallery into the roots (Fig. 8), (Smith,1961; Wood,1963;[5,6]).

Smith (1961) stated that the pupal period lasts about a week. The callow adults remain in the pupal cell about one week until the exoskeleton hardens and color changes to a dark reddish-brown. The new adults congregate and remain in the gallery area for a few days and finally bore out through the bark with many adults using the same exit hole. The length of the adult life may be as long as several months when actively feeding (Hopkins,1909a; Smith, 1961; Wood,1963;[5,6]).

The flight habits of the adults are little known after emergence from the galleries. Smith (1961) observed flying activity early in the spring after several warm days with records of dispersal of more than 10 miles. In Mexico a local resident stated that he had observed D. frontalis and D. valens flying together just after sundown in the fall months in swarms so tight that he could catch 20 or more beetles with one sweep of his hat. The flight relationship of the two insects is not known.[5,6]

Ecology. The ecology of bark beetles is discussed

by Rudinsky (1961, 1962). He stated that all bark beetles are similar in that, except for a short flight period, they complete their entire life cycle in their galleries under the bark. The flight serves for dispersal of the population and location of new food and shelter. D. valens is usually a secondary pest on standing trees and it also attacks stumps. Attacks may occur on apparently healthy trees after a population has built up in stumps on freshly logged area or in other available sources first attacked by other species of bark beetles.[5,6]

Rudinsky (1962) discussed factors influencing bark beetles larval development such as food, space, fungi, temperature, and moisture. Even though the larvae are isolated mechanically from the external environment temperature and moisture affect the individuals and the dynamics of the population.

Food and space are not a definite problem to D. valens since the area of attack at the base of trees is not invaded by other insects during development. Intraspecific competition may occur though none was observed. D. valens has an advantage over other species of the same genus because it is highly ploy phagous.[5,6]

Fungi and yeasts are usually associated with bark beetle epizootics and may aid in attraction and have nutritional value. Proteins are considered to be very important in influencing rate of development (Rudinsky, 1962).

Temperature is of great importance in rate of development and influences the number of generations per year. D. valens is exposed to a wide temperature range due to its extremely wide distribution. The temperature of its immediate environment may be very different in different locations depending on the position of the tree in relation to sunlight or shade. The thick bark at the base of trees offers more protection, and when the gallery extends below ground level the temperature remains fairly constant.[5,6]

Moisture and temperature together influence the rate of development. High moisture content in trees may prevent attack and delay larval development. Oviposition is also delayed when the sap output is high due to abundant moisture (Rudinsky, 1962).

Dispersal flight by D. valens is primarily for location of suitable food trees. The adult is known to be attracted by the odor of turpentine which influences selection of a host tree (Rudinsky, 1962).

The population density of this beetle depends upon the abundance of trees attacked by primary bark beetles and the presence of stumps after sizable logging operation. Many adults die during the initial attack on healthy trees, in the abundant resin flow that healthy trees are capable of exuding. The competition for food between broods may reduce the number of larvae (Smith, 1961;[5,6]).

Control. Little is known concerning possible

biological control of D. valens. Woodpeckers have been observed feeding upon the larvae and pupae. Insect parasites, predators, and pathogens are known to destroy larvae and pupae, but have not been identified (Smith, 1961).

Forestry sanitation methods can be useful in applied control. Among these are: prevention of damage to trees, especially during logging; avoiding the piling of green lumber or logs near healthy trees; removal of bark from freshly cut stumps; and removal of trees injured by wind, lightning, etc., and primary bark beetles. Addition of water and fertilizer to the soil also reduces beetle attack (Smith, 1961).

Smith (1961) reported chemical control was first applied by placing carbon bisulfide into the gallery entrance hole in order to fumigate the beetle. Insecticidal sprays such as BHC used for D. terebrans would probably be effective on D. valens. Latest recommendations call for spraying the basal portion of the trees with diesel oil and BHC. This will prevent additional attacks for several months and kill most of the insect stages in the tree. The spray should be applied up to one meter from the ground or to the highest point of attack (Smith, 1961).

DeLeon (1942) discussed the possibility of mechanical control by chiseling out the insects and painting the wound. He also reported chemical control by injection of fumigants such as ethylene dichloride and carbon disulfide

with a syringe into the galleries to kill the insects. Other more modern insecticidal fumigants would probably work equally well.

In the state of Chihuahua, Mexico where the insect was a primary pest on small pines of 3-10 cm basal stump diameter, mechanical control was partially effective.[2,3] Control consisted of removing the entire tree from the ground and peeling the bark from the tree, allowing sun's heat and drying to kill the insects still in the bark or those which fell out on the ground.[2]

Laboratory rearing. The bark sandwich method of rearing D. valens has been used in the laboratory. Bedard (1933) used sections of bark already containing broods of beetles. These sections were held together between two pieces of glass by elastic bands. Kaston and Riggs (1937) used essentially the same method but instead of elastic bands they used a wooden press. Kaston and Riggs (1937) considered Bedard's (1933) method inadequate since the elastic band did not give enough pressure to hold the bark tightly against the glass. The wooden press, however, produced excessive breakage of glass. Warren (1958) used a similar method except that the bark was cut from the tree by a large circular punch and a larvae placed in a separate hole cut in the circular piece of bark. . Rodriguez[4] successfully placed D. frontalis in a bark sandwich section held between two glass plates by wooden presses, strong

clips, and rubber bands. Clark[8] mentioned that a homogenate method used for D. brevicomis was successful. Warren mentioned that a bark homogenate method was not satisfactory. However, Stark[7] reported a successful modified artificial diet being used for D. frontalis. Rose[6] found the bark sandwich method successful for D. valens when extra strong rubber bands were used to hold the bark sandwich together.

Materials and Methods

Study areas. The area of bark beetle epizootic under study from 1962-3 was in a mountainous region 60 miles northwest of Mexico, D. F. in the region of Santiago Tlazala, near the town of Nicolas Romero in the State of Mexico. This forest was composed of Pinus leiophylla, P. montezumae, and P. patula. Over 90% of the trees were P. leiophylla. The epizootic began in November 1961 in four or five trees.[4] Fourteen months later, January 1963, when a control project was started, the number of dead and attacked trees exceeded 3,000. These trees were harvested and the bark peeled and burned. The epizootic was reduced by December 1964 to a few scattered trees with very low beetle population so control operations were discontinued.[4] Both natural causes and mechanical control operations caused the epizootic to decline.

A second epizootic area studied was in 1963-4 in a flat land pine plantation composed of the same tree species

in about the same relative abundance as in the mountainous area studied a year earlier. This area was located 90 miles east of Mexico, D. F. on the Ex-hacienda Mazanilla, five miles from the town of Puebla in the State of Puebla. The bark beetles had been in the general area for many years producing repeated epizootics in the forest.[3] The plantation was in an advanced stage of the epizootic in January 1963, but declined to a low level in December 1964 due to natural causes and mechanical control operations.

The bark sandwich. The bark sandwich used in laboratory studies was formed by placing a piece of bark about 12 X 8 cm from Pinus leiophylla, with cambium and inner bark intact, that were held between two pieces of glass, 20 X 12 cm X 5 mm, together by strong rubber bands. The larvae from one family were collected in the field and placed in a hole, about a two cm square, in the inner side of the fresh clean bark. The sandwiches were made in the field and placed in incubators on the same day. The larvae collected were generally in the same instar. Cotton was placed around the edges of the bark between the pieces of glass to retain and hold moisture which was applied as needed. The bark was changed when the developing larvae consumed all the inner bark or the inner bark became heavily damaged by fungous growth. All stages were easily observed through the glass while feeding on the surface of the inner bark (Fig. 8).

Incubators. Six growth chambers were used in the laboratory to house the sandwiches in order to observe insect development at six different temperatures. A standard domestic type refrigerator was set at 8.5 C while table model laboratory, incubators, about 2 X 3 X 2 feet, were held at 15, 20, 25, 30, and 35 C for the temperature study.

Problems encountered in the laboratory. The temperature in the incubators used to rear D. valens did not vary more than 1 C from the stated temperature except for 2 days when the outside temperature was colder than normal and the 15 C incubators were almost 2 C below the stated temperature. Adults from both the field and laboratory failed to oviposit in the sandwich cells. The adults possess the capacity to withhold their eggs until proper oviposition condition exists. A high percentage of hatch, however, was obtained from field collected eggs transferred to clean bark in the sandwiches. Most larvae fed on the surface of the inner bark and were readily seen through the glass. Some larvae bored into the inner bark when food became scarce or undesirable at the cambium because of fungous growth. These larvae were not visible through the glass. The larvae were transferred to new sandwiches when fresh food was needed but some delay in development may have occurred if food became scarce or deficient before transfer. All fresh bark was accepted by the larvae but the quality of the food and its possible effect upon development was not known.

Large numbers of mites were often attached to adults and larvae in all the sandwiches. The number of mites was reduced when changing sandwiches for new food, but they quickly increased again. They did not seem to harm the larvae or adults, but it is possible that some of them did reduce egg hatch by predatory action. They appeared to be feeding on excrement, frass, and fungi in the galleries.

The fungi probably lowered the quality of the inner phloem as food and delayed development of the larvae. Also it is possible that the fungi could have increased larval growth by addition of proteins and vitamins to the food, although Hetrick (1949) and Holst (1937) state that fungi are not necessary for larval development.

Nematodes of Rhabiditis sp. and Ditylenchus sp. were observed feeding in the frass with the larvae. Once nematodes were observed inside a dead larval body. The population of nematodes varied widely in different galleries. Unidentified bacteria also were found in dead larvae. Mites, nematodes, fungi, and bacteria, as well as exposure to light, escape from the sandwich, and handling, all probably caused some mortality of eggs, larvae, pupae, and adults. A species of clerid larva collected in galleries in the field and laboratory was observed preying on the eggs and larvae.

Field temperature studies. Temperatures were recorded with copper constantan thermocouple junctions in the beetle's environment in the pine plantation on the

Ex-hacienda Manzanilla near Puebla, Mexico. Temperatures were recorded on four typical, sunny, clear days during the cool season (January 21-22) and also during the warm season of the year (May 14-15). Temperatures usually were recorded at hourly intervals during the daylight hours and every two hours or more at night.

Air temperatures were recorded one meter above the ground level. Duff temperatures were taken within the thin litter of undecomposed pine needles on the ground. Soil temperatures were taken at a depth of 10 cm below the surface of the ground. Subcortical temperatures were taken beneath the bark of a D. valens infested Pinus leiophylla tree of about 18 inches DBH. To accomplish this, four holes were chopped through the bark, at ground level, on the north, south, east, and west sides of the tree. A thermocouple junction was then inserted an inch or more along the cambium into the gallery at the hours shown in Appendix 8 and 9. Since the entrances to the galleries were exposed, air circulation may have influenced some of the subcortical temperatures recorded.

Laboratory Results

Sex ratio. The males were readily identified by the heavy pigmentation along the angular rear margin of the enlarged seventh tergite (Lyon, 1958). This feature was readily seen and easy to use.

The insects were collected at random from the galleries in the field during the dry season. Groups of 50 adults preserved in 90% alcohol constituted a sample to determine sex ratio.

Sex ratio results of adult Dendroctonus valens.

Sample No.	Females		Males	
	No.	%	No.	%
1	22	44	28	56
2	28	56	22	44
3	35	70	15	30
4	36	72	14	28
5	24	48	26	52
6	29	58	21	42
Total	174	58	126	42

The sex ratio of these beetles was 58:42% females over males. The species was typically monogamous, but occasionally two females were found in a gallery with one male.

Larval instars. The number of larval instars was determined from head capsule measurements. These larvae were collected in the field or laboratory and preserved in 90% alcohol until measured. The larvae were first separated into six groups with the aid of a 0.5 mm quadrate ocular micrometer. The final exact measurements of all the larvae were taken with a linear ocular micrometer. The measurement of the six groups follows:

Larval instar determination of Dendroctonus valens.

Instar & No.	Diameter mm	Standard Deviation	Mean
I- 68	0.40-0.48	0.20	0.44
II-100	0.50-0.65	0.58	0.57
III-100	0.68-0.85	0.78	0.76
IV-100	0.90-1.20	1.01	1.06
V-100	1.25-1.55	1.46	1.28
VI-100	1.60-1.90	1.67	1.68

These measurements were used to identify instars of live larvae in the glass bark sandwiches. The cast skins and white head capsules of newly molted larvae observable in the sandwiches were used to verify the above findings. The larvae in the sandwiches were measured daily and observed within the various larval instar groups measured.

Development at constant temperatures. The rate of development of an insect under controlled temperature conditions can give precise knowledge of the various stages, their number, and duration. Under such conditions it was possible to establish the age of developing individuals at constant temperatures of 8.5, 15, 20, 25, 30, and 35 C.

It was more convenient to determine the duration of various stages and instars by using short term bark sandwich experiments than by rearing larvae in masses in logs. This was especially true at the lower, colder temperatures where the stages are of long duration. The laboratory data were used as a check against field observations and experiments.

The eggs in various stages of development were

brought in from the field. Hatching began in the sandwiches within one or two days. The newly hatched or moulted larvae were recognizable by the white head capsule, which changed in one to two hours to an orange-brown color. The body appears transparent and the digestive system becomes darker upon the intake of food. The abdomen has a typical rounded form without legs. The larvae pass through five to six larval instars, similar in form and color (Fig. 7). The mature larvae become quiescent during the non-feeding prepupal stage. The gut is emptied and the abdomen becomes white and contracted. The pupae are white in color.

The data recorded for the various constant temperatures are presented as the minimum developmental time for a given instar or stage in the sandwich group to moult to the next instar or stage. This is not necessarily the actual minimum developmental time as determined by observing the length of time individual live beetles spend in a particular instar or stage. The duration of any instar or stage was based on the total number of days the instar or stage was observed in the sandwiches (Tables 1, 2; Figures 1, 2; Appendices 1-7). Several individuals often completed the instar or stage on the same day, but the number of individuals was not recorded.

There was much mortality of insects in each sandwich. No insects developed completely from egg to adult in the laboratory. No information about eggs was recorded

since adults would not oviposit in the laboratory. One sandwich at 15 C showed development from the first instar to adult. Many eggs and larvae of all instars were brought in from the field at intervals and placed in the sandwiches to provide information for all stages. A sandwich was generally made up of larvae of the same instar and from the same family.

A definite sixth instar occurred at 8.5, 15, 25, and 30 C but not at 20 C. The sixth instar was most prevalent at 8.5 C. Sixth instar larvae transformed to adults at 15, 25, and 30 C. Sixth instar larvae formed pupal cells at 8.5 C, but none had transformed to pupae when the experiment was terminated after 70 days. The abdoment of these larvae, at 8.5 C, were noticeably larger than on larvae at higher temperatures. When transferred to room temperature at 25 C all these 8.5 C reared larvae died within a few days. It is not known if the differences in number of instars was due to sex differences.

All stages of the insect died within one or two days at 35 C. However, all stages were reared in sandwiches at 15, 20, 25, and 30 C.

The total number of insects at the start of all sandwiches was 1,758 plus uncounted eggs (App. 3-7). Mortality reduced this total approximately 80% or more by the end of the experiment. This mortality was probably caused primarily by fungi which deteriorated the wood. Each

individual sandwich was continued under observation until all had transformed to adults or no normal appearing larvae remained.

D. valens showed a general tendency to develop in fewer days as the temperatures increased from 8.5 through 25 C. At 30 C, however, the minimum developmental time was longer in the second and fifth instars, whereas the duration of the third instar was longer. Otherwise, the developmental periods at 30 C were shorter than at lower temperatures, suggesting that this temperature was near the upper edge of the effective zone for development of this insect. The favorable development zone was between 20 and 30 C (Tables 1, 2). The optimum developmental temperature was probably between 25 and 30 C. The 15 C was in the effective zone of development but at that temperature most instars and stages took about 10 days longer to develop. The developmental differences, as observed at constant temperatures in the laboratory, would allow between one-half to four generations a year. Probably, two generations a year usually occur in the colder pine covered mountainous regions of Central Mexico.

The daily rate of development (1/time X 100) was plotted on a probit scale to show the per cent of development per day at all temperatures between 8.5 and 30 C in a straight line relationship (Figs. 1, 2). With regard to minimum developmental time, there was a rapid increase in

development with an increase in temperature. The fifth instar in both figures had the slowest developmental rate at all temperatures. The data on the fifth instar also included the prepupal stage which lasts several days. The pupae and callow adults had the most rapid developmental rate of all stages at all temperatures (Fig. 2). The first and second instar exceeded developmental rate of pupae and callow adult for minimum developmental time at 20, 25, and 30 C (Fig. 1). The sixth instar had approximately the same developmental rate of about 5% at 15, 20, and 30 C and was not plotted. The physiology of the insect and its growth hormones are probably responsible for the developmental variability because metabolism rates and release of growth hormones differ at different temperatures and different instars or stages.

Figure 3 represents a duration graph in the average number of days for development taken from Tables 1 and 2. The duration of the various instars and stages are shown based on the first and last insect to moult in the sandwich group. The minimum developmental time to complete a given instar or stage also can be interpreted from the graphs by counting the days from the start of each instar or stage to the start as the following instar or stage. The number of days from egg hatch to appearance of adults was approximately 165 days at 15 C, 105 days at 20 C, 100 days at 25 C, and 95 days at 30 C. At 8.5 C the insect could not

develop from egg to adult. Never the less, eggs did hatch and larvae did develop from one instar to another.

Field Results

Attack habits and evidence of attack. In Central Mexico D. valens was most frequently associated with D. frontalis. D. valens always attacked a tree after D. frontalis. The attack of D. valens upon a tree may extend for a period of over a year since the bottom of the tree remains alive longer than the top due to more resin and moisture from the roots.

Principally attacked were freshly cut stumps up to several months old, and bases of dying or weakened trees. Under these conditions the pest produces its largest populations which may then become a threat to nearby healthy trees. Most attacks on healthy trees were unsuccessful. Even with trees scarred for resin collection, the attacks of D. valens amounted to only an irregular gallery excavation and resultant scar or "cat face." No oviposition was observed to occur on "turpentined" trees. Attacks on healthy trees may attract other bark beetles which are more potential killers of the trees. The beetle galleries of D. valens must encompass nearly the entire circumference of the tree to be fatal. The foliage color usually had turned yellow soon after the attack by the primary bark beetle, before D. valens entered the tree. D. valens also entered trees with

a light to dark reddish brown needle color.

The female enters the tree and usually bores downward after a preliminary upward bore, however, one to four adults of both sexes may be in the same gallery. Usually one male and one female only were present. Several observations revealed two to three females with one male in the initial gallery stages only. The resin, which contains boring dust and excrement mixtures were whitish to reddish in color, depending upon time of attack, and were pushed out of the tree by the male (Fig. 17). This exudation is the first conspicuous evidence of beetle attack. Larger trees (50 cm or more DBH), could support as many as six families around the basal circumference. The adult vertical gallery, usually leading into the roots, was observed upon removal of the bark and a fan-shaped larval gallery was also evident in advanced stages of attack.

The development of D. valens in the forest normally takes place under a variety of environmental conditions. A great diversity of temperature conditions results from latitude and altitude differences, exposure of the bark to the sun, stand composition, forest canopy, tree vigor, bark thickness, and seasonal conditions. The host tree may play an important role in the insects' development due to differences in moisture, sap flow, sap content, and nutrients.

No attempt was made to estimate the length of

various stages and instars in the field. A great overlapping of broods from several galleries was often encountered. One gallery contained 189 larvae, feeding together, from as many as four families.

The great overlapping of stages in the same tree or same area made it difficult to determine the number of generations per year. All stages of the insects were found throughout the year in Central Mexico. From field observations and laboratory results, two generations a year were estimated for Central Mexico.

Temperature studies. Temperature studies were conducted in the environment of D. valens on four, clear sunny days (Figs. 4-6, App. 8,9), two in January and two in May. The Figures show the variations and extremes of temperature that occurred during typical sunny weather in the cool and warm seasons. The monthly temperature and rainfall records for the years 1958-64 at Puebla, Puebla, Mexico are shown in Appendix 13 and 14. They indicate when the cool and warm seasons and the wet dry seasons occur.

The air temperature one meter above the ground level, four subcortical temperatures at ground level, the duff temperature just below the surface litter, and the soil temperature 10 cm below ground level were recorded at the same time.

Under the existing forest canopy, which somewhat reduced the warming effect of the sunlight on bark and earth

surfaces, the subcortical temperatures on the tree trunks followed the air temperatures fairly closely (Figs. 4,5), especially during the daylight hours. However, during the day the air and various subcortical temperatures fluctuated considerably in relation to each other. No doubt, moving patches of sunshine and shadows moving across the bark over temperature recording points, and possibly passing clouds, caused most of these fluctuations by alternately warming and cooling these places. At night, there was fewer of these temperature fluctuations and none of the subcortical temperatures fell as low as the air temperature. In January, the maximum subcortical temperature during the day was 25.6 C. The minimum temperature at night was 10.0 C. In May, the maximum and minimum subcortical temperatures were 28.9 and 5.6 C respectively.

None of these temperature extremes in bark above the ground are lethal to D. valens. They may, dependent upon the extent to which they recur, retard the beetle's rate of development. Such recurrences probably are typical for a locality and help account for the existing rate of insect development there.

As expected, duff temperatures rose much higher than subsoil temperatures during daylight hours. This was due to the direct rays of the sun, in early afternoon, being absorbed by the dark colored, thin layer of litter.

At a depth of 10 cm, the subsoil temperature

fluctuated much less during the day than the air and duff temperatures (Fig. 4). It also varied within a much narrower range between day and night, subsoil temperatures remaining about 5 C lower than the subcortical temperatures during the day and about 7 C higher at night (Figs. 4,5). The 10 cm of soil acted as an insulator and retarded temperature changes. In view of the subsoil and subcortical temperatures recorded at ground level, D. valens probably experiences narrower extremes of temperature in galleries that extend below the ground than in galleries that are above the ground level. Thus, beetle development may proceed at different rates in bark above and below ground.

Since a large overlapping of broods was encountered in the area, it was difficult to estimate the number of generations a year in Central Mexico. All stages were found throughout the year. From the information obtained during the laboratory rearings and field observations, the beetles probably complete at least two generations a year.

Summary

The bark beetle Dendroctonus valens Lec. (Scolytidae) is generally a secondary pest of stumps and the basal portion of trees that are under attack by a primary bark beetle or which are weakened by other factors. The association with Dendroctonus frontalis Zimm. with D. valens was most frequent in the pine forests of Central Mexico and, under

these conditions, D. valens was of no significant economic importance. The beetles do attack trees which appear to be healthy, but with little success. The species passes its entire life cycle in the inner bark of the tree except for short flights to disperse and locate new host trees.

The sex ratio was 58% females to 42% males based on an examination of 300 parent and progeny adults collected during the dry season from galleries in the field. The ratio may account for the fact that more than one female was occasionally found in with one male in some galleries at the beginning of their construction.

Five to six larval instars occur during development. At 20 C the sixth instar did not occur in any of the sandwiches. In many of the sandwiches, at other temperatures, the sixth instar was not observed. At 8.5 C the sixth instar was held for about 70 days but did not pupate.

Subcortical temperatures recorded in the galleries of standing trees for limited periods usually were close to air temperatures under field conditions. The temperature recordings in January and May were somewhat similar. The fluctuation of temperature during the day was probably caused primarily by the sunlight and shadows moving through the forest canopy. Soil temperatures (10 cm deep), fluctuated least of all in relation to air temperatures and remained between 12.2 to 20.0 C for both recording dates. Consequently, D. valens experiences little developmental

fluctuations since adult and larval galleries usually extend underground.

The laboratory studies consisted of daily examination of all stages in "sandwich" observation cages placed in constant temperature chambers. The temperatures were set at 8.5, 15, 20, 25, 30, and 35 C. The larvae reared at 8.5 C did not complete development during the experiment. All stages at 35 C died in one or two days.

The insects showed a general tendency to develop faster as the temperatures increased from 8.5 to 25 C. The results suggested that 30 C was near the maximum effective limit for this insect. The favorable development zone was between 20 and 30 C. The optimum developmental temperature was probably between 25 and 30 C. The 15 C temperature was in the effective zone of development but most instars and stages took about 10 days longer to develop at this temperature. The possible number of generations occurring in Central Mexico was estimated to be two, but they overlapped, with all stages present throughout the year.

Conclusions

Under constant temperatures in the laboratory it was possible for one-half to four generations of Dendroctonus valens Lec. to occur in a year. The minimum time for the life cycle to be completed from larvae through callow adult, was 163.2 days at 15 C, 104.0 at 20 C, 104.5 at 25 C,

and 97.0 at 30 C. At 8.5 C the larval stage continued for 247 days without pupation. Two generations probably occur annually, in the relatively temperate climate of Central Mexico, with all stages of the insect developing throughout the year.

Five and six larval instars occurred in both the field and laboratory reared insects which transformed to the pupal stage. It is not known why both five and six instars occurred. The difference in the number of instars might be due to development at the various constant temperatures under laboratory conditions, moisture, hormone secretions within the larval body, sex differences, or a combination of these factors.

From the laboratory experiments of rearing the insects between 8.5-35 C, the favorable developmental zone probably occurred between 20 and 30 C. At 35 C all insects died and at 8.5 C no pupation occurred. A slight decay occurred at 30 C in comparison with 25 C, suggesting 30 C was near the maximum effective zone for this insect. The 15 C was in the effective zone but produced a significant delay in development. The optimum developmental temperature was probably between 25 and 30 C.

S E C T I O N I I

THE BIOLOGY AND ECOLOGY OF THE SOUTHERN PINE BEETLE (SMALLER MEXICAN PINE BEETLE), *Dendroctonus frontalis* (= *mexicanus*) Zimm. IN CENTRAL MEXICO

(Coleoptera:Scolytidae)

Introduction

The other member of the genus Dendroctonus that was studied was Dendroctonus frontalis (= mexicanus) Zimm. D. frontalis is known as the Southern Pine Beetle in the United States and the Smaller Mexican Pine Beetle in Mexico. D. frontalis is a primary bark beetle attacking healthy trees by itself during epizootics which usually start with attacks upon weakened trees. Even the more resistant and vigorous hosts succumb to large numbers of the beetles during epizootics. This beetle causes a greater loss to timber in Mexico than any other insect.[3,4] The beetles usually are found in the forest in epizootics of different size. Infestation of beetles in Mexico may develop from a single dead tree to an epizootic that kills thousands of trees in three or four years before subsiding.

The purpose of this research was to study the biology and ecology under both laboratory and field conditions. The need for knowledge on D. frontalis in Mexico stimulated this investigation. The emphasis in the laboratory was on the response and development at different temperatures. The emphasis in field research was on the attack habits and evidence of attack, population fluctuations, and existing temperatures in the beetles niche which influence the insects development.

Analysis of Literature

Economic importance. Dendroctonus frontalis is one of the most important forest insects in North America, north of Nicaragua. In the southestern United States, Mexico, Guatemala, and Honduras, it is considered a forest insect pest of primary importance (Dixon and Osgood,1961; Ketcham and Bennett,1964;[3,4]). A recent epizootic in Honduras killed over 5,000,000 acres of timber from 1962 to 1964 (Fox et al., 1964), and was considered beyond feasible control measures one year prior to the decline.[8,9,11] This epizootic was reported in early 1966 to have subsided primarily from natural causes.[9,10]

The epizootics vary in size and intensity. The beetles kill attacked trees which then are rapidly destroyed by fungi and secondary insects. Consequently great economic and aesthetic loss results from these epizootics. The wood has no commercial value, due to fungous deterioration, six months to two years after being attacked. The extent of deterioration depends on the size and locality of the tree attacked.[3,4] In Mexico, almost 90% of the insect destruction to pine forests is caused by D. frontalis (Moreno,1963).

Distribution. The geographic distribution of D. frontalis is shown in Figure 16. The distribution of its two synonyms arizonicus and mexicanus, and an isolated population of D. frontalis in southern Mexico, Guatemala,

and Honduras, are also shown in Figure 16 (Martinez,1948; Perry,1951; Moreno,1954; Schwerdtfeger and Becker,1955; Bartholumew,1957; Dixon and Osgood,1961; Moreno,1963; Wood, 1963; Ketcham and Bennett,1964;[11]).

In the eastern and southern United States, D. frontalis is distributed from New Jersey to eastern Texas. D. frontalis (= arizonicus) occurs in an area about 600 miles west of D. frontalis extending from western Texas into New Mexico, Arizona, and parts of southern Colorado. D. frontalis (= mexicanus) is found in Mexico from the northern state of Chihuahua south to Oaxaca. D. frontalis (= mexicanus) or possibly another species, occurs isolated south of the Isthmus of Tehuantepec in southern Mexico, Guatemala, and Honduras bordering Nicaragua (Fig. 16).

D. frontalis (= mexicanus) in Mexico has its greatest population in the central region in the states of Hidalgo, Mexico, Morelos, Puebla, Toluca, and the Federal District (Perry,1951; Moreno,1963). Moreno (1954) reported attacks also occurring in the states of Aguascalientes, Chihuahua, Durango, Guanajuato, Nuevo Leon, Queretaro, and Veracruz, Mexico.

Host trees. D. frontalis attacks Pinus echinata Mill., P. elliottii Engelm., P. densiflora Sieb. & Zucc., P. glabra Walt., P. palustris Mill., P. pungens Lamb., P. resinosa Ait., P. rigida Mill., P. serotina Michx., P. strobus L., P. taeda L., P. virginiana Mill.; and Picea

abies (L.) Karst., and P. rubens Sarg. in the southeastern United States (Kowal,1960; Thatcher,1960; Dixon and Osgood, 1961; Wood,1963). Kowal (1960) reports that the preferred species, in which large populations were produced and epizootics occur, were Pinus echinata, P. rigida, P. taeda, and P. virginiana.

The only host known to have been attacked in Arizona and New Mexico was Pinus ponderosa Laws. (Hopkins, 1909a; Wood,1963).

The hosts attacked in Mexico were Pinus ayacahuite Ehr., P. leiophylla Schl. & Cham., P. montezumae Lamb., P. patula Schl. & Cham., and P. teocote Schl. & Cham. Pinus leiophylla was the preferred host in Central Mexico (Perry, 1951; Moreno,1954; 1963;[3,4,5]).

The hosts attacked in southern Mexico and Guatemala were Pinus ayacahuite, P. pseudostrobus Lindl., and P. rudis Endl. with P. ayacahuite the preferred host (Schwerdtfeger and Becker,1955), while in Honduras Pinus oocarpa Schiede was the preferred host over P. caribaea Morelet and P. pseudostrobus.[10,11]

Taxonomic position. Taxonomists have caused many problems in describing and revising the species of the genus Dendroctonus Erichson (1836). Revisions and descriptions have been published by Eichoff (1864), Chapuis (1869), LeConte (1876), Blandford (1897), Hopkins (1909b), and Wood (1963). LeConte (1876) expressed the difficulty

of species recognition in his revision of the genus. He stated, "If I have failed to indicate more strongly the differences between species, it is because they are not distinguishable by any prominent or definite characters; and the student who may have difficulty in identifying the species as here defined would have almost equal difficulty if the specimens in my collection were before him."

On the basis of new anatomical characteristics of the beetles and biological characters of brood galleries, Wood (1963) reduced the number of species in the genus Dendroctonus from 24 to 14. The biological characters used consisted mainly of "egg gallery, position and arrangement of egg niches and grooves, and the character and position of larval mines." His work was hampered mainly by his adherence to the typological species concept, based on morphological differences. He included Dendroctonus mexicanus Hopkins and D. arizonicus Hopkins as synonyms of D. frontalis Zimm.

I believe Wood (1963) had underestimated the importance of host preference in his generic revision. He states "All species, with the possible exception of aztecus, are widely distributed geographically but are rather limited in hist range. All species, with the possible exception of pseudotsugae and valens, confine their attacks to a single genus of host trees, and usually to a limited group of species within that genus, except during epidemic outbreaks

when almost any conifer may exhibit signs of attack." In my literature analysis I have found that known and preferred host trees of geographically isolated populations do not overlap in the distribution of D. frontalis, (= arizonicus), (= mexicanus), and the isolated southern population of beetles in southern Mexico, Guatemala, and Honduras (see distribution map Figure 16). Therefore Wood (1963) contradicts his statement when he synonymizes D. mexicanus and D. arizonicus with D. frontalis. He has disregarded the importance of host trees at the species level.

Hopkins (1909b) in his revision of Dendroctonus used biological and anatomical characters to distinguish and delimit the species in this genus. The biological characters used were the habits, host preference, and distribution of the species.

More recent investigations by Smith (1961b, 1963, 1965) have shown that physiological differences exist between certain species of bark beetles. He conducted reciprocal toxicity tests with pine resin vapors on three species of Dendroctonus bark beetles; D. brevicomis, D. ponderosae (= jeffreyi), and D. ponderosae (= monticolae). The latter two were synonymized by Wood (1963). Results showed that these bark beetles could survive and reproduce in the saturated resin vapors of their host trees, but not in those of the non-host trees. Thus Smith (1965) states, the latter synonymized species appear to have enough physiological

difference "to justify the maintenance of biological entities."

D. frontalis, (= arizonicus), and (= mexicanus) appear to be cryptic species. Their geographic isolation, preference for different host trees, and possible physiological differences in response to host resin vapors is a basis for species division of this complex. I also suggest that a new species could probably be described based on the geographically isolated population in southern Mexico, Guatemala, and Honduras. This population has different preferred hosts from the other species (Fig. 16).

Further research is required to find additional characteristics to separate the species. D. frontalis will be used in this dissertation since sufficient evidence to substantiate my suggestion is unavailable. The multidimensional species concept studies such as: breeding tests, resin vapor toxicity tests of host and non-host trees, numerical taxonomic studies, chromosome determinations, biochemical analysis, and serological tests should be used for any future revision of the genus Dendroctonus.

General description of the stages. The emerging adult is pale in color, as is common among bark beetles, but soon becomes dark reddish brown to almost black as the body hardens (Kowal,1960; Dixon and Osgood,1961). The adult measures between 2.2 to 4.2 mm in length (Thatcher,1960; Dixon and Osgood,1961). Wood (1963) gives the male length as 2.3-4.5 mm (average about 3 mm) and 2.4 times the width.

The body is cylindrical and slender, with a longitudinal groove on the front. The head has prominent lateral elevations (Wood,1963). The legs are short and the elytral declivity convex (Dixon and Osgood,1961). Wood (1963) states that specimens from southern Mexico tend to average nearly 1 mm larger, and are somewhat darker in color than those from the eastern United States.

The egg is oblong to oval, opaque white, and about 1.5 mm long and 1 mm wide (Dixon and Osgood,1961).

The larvae are grublike, legless, wrinkled, and about 2 mm in length upon hatching (Dixon and Osgood,1961). The full grown larvae are about 5 mm long with a reddish brown head capsule. Four instars are indicated from head capsule measurements (Fronk,1947).

The white fragile pupae, distinguishable by the large head and prothorax resembling that of the adult, are 3 to 4.2 mm long (Kowal,1960; Dixon and Osgood,1961).

The soft, whitish callow adult remains in the pupal cell where hardening and darkening of the exoskeleton occur. The color changes to yellowish brown, to reddish brown, and finally to dark brown or almost black about a week before the adult beetle is ready to emerge from the host tree (Anderson,1960; Kowal,1960; Dixon and Osgood,1961). Older adults, a month or more after emergence, are light to dark brown with the elytra paler than the rest of the body (Kowal,1960).

Biology and habits. In Mexico, the insect passes the cool dry winter season in all stages. The life cycle in warmer southern latitudes, from the southern United States through Mexico to Honduras, is probably not interrupted as it is in the northern latitudes of the United States (Perry,1951; Moreno,1954; Thatcher,1960; Dixon and Osgood,1961; Wood,1963;[9]).

The length of the developmental cycle varies considerably. Development in Mexico requires about 30 to 80 days (Perry,1951). Ketcham and Bennett (1964) reported 11 to 12 generations in Honduras. There were seven to eight generations in recent epizootics in eastern Texas.[9] Entomologists in the United States and Mexico have reported from three to six generations with considerable overlapping (Hopkins,1921; MacAndrews,1926; Perry,1951; Moreno,1954; Fronk,1947; Kowal,1960; Thatcher,1960; Dixon and Osgood, 1961; Wood,1963).

The emerging adults may attack nearby trees or fly considerable distances (Hopkins,1921; MacAndrews,1926; Perry,1951; Wood,1963). The true flight habits of this insect have not been determined (Thatcher,1960; Dixon and Osgood,1961). Southwood (1962) described Scolytids as occupants of temporary habitats and added that subsequent generations usually reach their hosts by flight with a purposeful form of migration rather than by random trivial movements. Flight activity has been reported to be at its

height in the afternoon with the peak of activity around 4 PM (Tsao,1966).

Usually the attack starts in the middle portion of the main tree trunk, continuing in both directions (MacAndrews,1926; Kowal,1960; Thatcher,1960; Ketcham and Bennett,1964). This insect may attack trees as small as 2-5 cm DBH during an epizootic (Kowal,1960; Dixon and Osgood,1961), but it usually attacks larger trees (Perry, 1951; Thatcher,1960; Dixon and Osgood,1961).

The species is monogamous and has a sex ratio of 1:1 (Fronk,1947; Moreno,1954). The female starts perforating the bark, followed immediately by the male who helps by pushing the flow of resin and frass out the entrance hole. They usually mate, before or shortly after attacking the tree, and copulation occurs on the bark before perforation (MacAndrews,1926; Fronk,1947; Thatcher,1960; Dixon and Osgood,1961).

When the resin flow is abundant, a short additional gallery is formed to the bark exterior beside the original entrance to handle the excess flow (Perry,1951; Thatcher, 1960; Dixon and Osgood,1961). Finally the insect reaches the bark interior where a small nuptial chamber is sometimes made (MacAndrews,1926; Moreno,1954). The female continues cutting a sinuous gallery through the cambium and phloem working from all angles (MacAndrews,1926; Moreno, 1954; Thatcher,1960). The male piles the sawdust and

residues in the posterior portion of the gallery, closing it, and leaves only a small space to continue work (MacAndrews, 1926; Fronk,1947; Thatcher,1960). The gallery is frequently connected to the exterior by ventilation holes which also become closed with sawdust as the gallery is continued (MacAndrews,1926; Thatcher,1960). The ventilation holes number from 8 to 15 per family (Moreno,1954).

The female extends the gallery about 2.5 cm daily, depending upon resin flow in the beetle's working area (MacAndrews,1926; Moreno,1954; Thatcher,1960; Dixon and Osgood,1961). Some galleries are enlarged rapidly while few eggs are laid while other galleries progress slowly with deposition of many eggs (MacAndrews,1926).

The eggs are deposited singly at intervals of 4 to 20 mm in small niches located alternately along both sides of the gallery wall (MacAndrews,1926; Moreno,1954; Kowal, 1960; Wood,1963). The female places the egg in the interior of the niche, packing them in both regurgitated and cut out wood frass and sawdust. The male helps by packing sawdust around the eggs (Fronk,1947; Perry,1951; Moreno,1954; Thatcher,1960). The female has been reported by various researchers to deposit an average of 20 eggs (Thatcher, 1960), 50 to 60 eggs (Moreno,1954), and 90 eggs (Perry,1951). Clark[8] reported a female reared in the laboratory without competition deposited 243 eggs in a gallery over one meter long. The length of the gallery varies from 5 to 48 cm

according to MacAndrews (1926), Perry (1951), and Moreno (1954). Clark[8] also reported that when two families were placed about two inches apart, the galleries encircled the log in a spiral always remaining from 2 to 3 inches apart. Egg laying lasts about 12 days during warmer weather in Mexico (Moreno,1954).

The parent adults emerge a week or more before their brood if they do not die in their galleries (MacAndrews, 1926; Perry,1951; Moreno,1954). The later habits of these parent adult beetles which emerge from their galleries are unknown (Thatcher,1960).

The egg eclosion takes place in three to nine days (Fronk,1947; Moreno,1954). The small larvae begin making galleries more or less perpendicular to the adult gallery always managing to avoid galleries of other larvae (MacAndrews,1926; Perry,1951; Wood,1963). The larval galleries in the initial stages are very narrow and limited to the inner phloem (MacAndrews,1926; Perry,1951; Thatcher, 1960; Dixon and Osgood,1961; Wood,1963). The larvae, as they increase in age and size, form an irregular oval shaped gallery (Fronk,1947), which may extend to the cambium (Wood,1963), or into the inner bark (Perry,1951; Kowal,1960; Thatcher,1960). Dixon and Osgood (1961) reported larval galleries measured from five to 20 mm in length while Moreno (1954) in Mexico gives eight to 10 cm as total length.

The larvae always consume their own exuvia (Fronk, 1947). The approximate duration of larval instars in Virginia, U.S.A. was reported by Fronk (1947) to be: first instar, 9 days; second, 9 to 13 days; third, 7 days; and fourth, 9 days. The larvae have been observed to complete development in 20 to 22 days in Central Mexico (Moreno, 1954) and a minimum of 25 to a maximum of 38 days in Virginia, U.S.A. (Fronk,1947).

The larvae extend the gallery to the exterior bark and prepare a pupal cell (MacAndrews,1926; Moreno,1954; Dixon and Osgood,1961), about 3 to 4.5 mm long (Fronk,1947). The pupal period lasts from 7 to 14 days (MacAndrews,1926; Fronk,1947; Moreno,1954; Thatcher,1960).

The young adults or progeny emerge immediately after they pass the callow or hardening period (Perry,1951), or build a short gallery in the outer bark before emergence (MacAndrews,1926; Thatcher,1960). Each adult generally makes its own exit hole (MacAndrews,1926; Thatcher,1960; Dixon and Osgood,1961). The emergence period of one brood of adults may extend from 10 to 32 days (MacAndrews,1926).

Population abundance. The influence of the physical environment, food, biotic factors, etc., upon D. frontalis have not been studied in detail. The biological cycle and most aspects of the biology are well known (MacAndrews,1926; Kowal,1960; Dixon and Osgood,1961).

D. frontalis is characterized by extreme population

fluctuations (Hopkins,1921; Fronk,1947; Kowal,1960; Thatcher, 1960; Dixon and Osgood,1961). Unfavorable conditions which weaken the host trees probably favor the increase in vigor and size of D. frontalis populations and stimulates severe attacks (Kowal,1960; Rudinsky,1962).

Temperature and moisture are of major importance in development of this insect (MacAndrews,1926; Fronk, 1947; Moreno,1954; Kowal,1960; Dixon and Osgood,1961; Rudinsky, 1961, 1962).

D. frontalis has been observed in severe attacks during drought periods, especially during the dry summer months of the year. Populations often decrease to enzootic conditions after the rainfall returns to normal, but they have also been observed to decrease before the rainfall returns to normal (Dixon and Osgood,1961). Flooding also has been observed to weaken the trees and predispose them to attack by the pest. Other observations indicate that heavy rain can also cause destructive mechanical injury to the insects (Thatcher,1960).

The stages of D. frontalis most resistant to cold were the eggs and pupae (Fronk,1947; Thatcher,1960; Dixon and Osgood,1961). Subcortical temperatures that were lethal were to immature stages of D. frontalis have resulted from exposure of logs to direct sun rays (MacAndrews,1926; Thatcher,1960; Dixon and Osgood,1961).

It is generally accepted that any circumstance that

weakens trees, renders them more susceptible to attack. Therefore the more intense and widespread the unfavorable factors are for the trees, the more probable a bark beetle epizootic will develop (Thatcher,1960).

Causal factors that can weaken host trees and predispose them to attack may be advanced age, poor soil or site conditions, drought, floods, snow and ice damage, wind damage, fire, lightning, attack by other primary bark beetles, fungus attack, attack by defoliating insects, mechanical damage by man, air pollution, atomic ionizing radiation, etc. (Graham,1952; Perry,1951; Thatcher,1960; Rudinsky,1962; Ketcham and Bennett,1964; Brower,1965).

The water content and resin pressure in the trees have shown significant correlation and influence upon the severity of attack on individual trees. The lower the water content and resin pressure the greater the danger of an attack or a population build up (MacAndrews,1926; Thatcher,1960; Dixon and Osgood,1961; Rudinsky,1962). The production of large amounts of resin, high resin pressure, and probably the composition of the resin aid the tree in repelling the attack. Resin odor resulting from the wounds made by the initial attackers aid in attracting later mass attacks by these insects on healthy trees. The initial attackers many times are killed by the resin flow (MacAndrews,1926; Perry,1951; Rudinsky,1962).

Many times the first insects that perforated the

bark were trapped and killed by the resin (Perry,1951; Thatcher,1960). During a severe epizootic, sheer numbers of beetles overwhelmed the trees attacked regardless of their condition (Thatcher,1960; Rudinsky,1961). In the periods of low population density, the only trees successfully attacked are those weakened by some factor other than the beetles (Rudinsky,1962).

Live wind-thrown trees are very attractive to this insect when the population density is at a low level (Thatcher,1960; Rudinsky,1962). Population increase in fallen trees was as great or greater than upon the live standing trees (MacAndrews,1926). Population studies of the proportion of exit holes in both wind-thrown and standing trees has shown a variation at 310 to 1500% increase in one generation (MacAndrews,1926; Moreno,1954; Dixon and Osgood,1961; Ketcham and Bennett,1964).

When weather conditions are favorable for the insect a weakened tree or group of trees, may cause a focus of infestation (Hopkins,1921; Perry,1951; Kowal,1960; Thatcher,1960; Dixon and Osgood,1961; Rudinsky,1961). The trees situated on the perimeter of an epizootic suffer continuous attacks (Hopkins,1921; MacAndrews,1926; Thatcher, 1960). The insects become more aggressive when the population becomes abundant. Neighboring trees are attacked regardless of their size, health, and vigor (Rudinsky,1961). The epizootic extends to new trees in

expanding concentric rings around the focus (Perry,1951; Moreno,1954), or in the form of fingers extending from the epizootic (Thatcher,1960).

The composition and density of the forest also determine susceptibility (Perry,1951; Moreno,1954; Dixon and Osgood,1961; Rudinsky,1961). Mixed forests that contain both non-preferred and preferred species, are less favorable for the development of epizootics of this pest than are pure stands of the preferred host (Graham,1951; Thatcher,1960; Dixon and Osgood,1961).

Host susceptibility to attack by D. frontalis often varies within the same species of Pinus. More vigorous trees are less susceptible to attack and succumb only to a large number of insects which produce fewer progeny due to heavy competition (Moreno,1954; Rudinsky,1961; 1962).

I stated (Puente,1964) that intensively attacked pines in Central Mexico were Pinus leiophylla and P. montezumae. P. montezumae had more than twice as many beetles attacking equal bark surface than attacked P. leiophylla. Perry (1951) suggested that an oleoresin drying differential which varies with species was responsible for differences in intensity of attack. I also stated (Puente,1964) that I had observed vigorous P. leiophylla individuals resisting the insect attack until a very high population of beetles in repeated attacks overcame them. In two epizootics, P. patula trees growing in mixed stands

with P. leiophylla were not attacked. Other observations on P. patula in mixed stands showed that the trees succumbed to the attack of the beetles. Some observations showed P. patula to be resistant to D. frontalis attack since all beetles attacking the trees were killed and the tree did not succumb to the attack.

Reduction of the epizootics is usually very rapid, occurring in a year or less. Factors such as low temperature and excessive rain, which increases the resin pressure and flow, have caused sudden population reduction of D. frontalis (Thatcher,1960; Dixon and Osgood,1961). There are no records that bark beetle epizootics have been completely destroyed by predators, parasites, or competitors (Thatcher,1960).

Associated organisms. The fungus Ceratocystis minor is commonly associated with the attacks of D. frontalis. This fungus causes "blue strain" and accelerates the death of the attacked trees since the fungus mycelium plugs the outer layers of the xylem cells (Thatcher,1960; Dixon and Osgood,1961; Rudinsky,1961,1962; Ketcham and Bennett,1964) within five to seven days after attack (Craighead and St. George,1938). The fungus is presumably essential in a symbiotic relationship with D. frontalis (MacAndrews,1926; Thatcher,1960).

It is generally believed that predators, parasites, and pathogens, although associated as control factors, do

not play an important role in the population fluctuations of this insect (Moreno,1954; Kowal,1960; Dixon and Osgood, 1961; Ketcham and Bennett,1964). Various biotic agents including birds, insects, mites, and nematodes have been reported to be in association with this beetle (Fronk, 1947; Kowal,1960).

Perry (1951) in Mexico observed the following pattern of attack: following invasion of the middle portion of the tree by D. frontalis, the base was invaded by D. valens; later Ips bonanseai attacked the crown portion of the tree. It has also been suggested that the intraspecific and interspecific competition of these bark beetles forces emigration in large numbers to find new host trees. Both types of competition in large populations of bark beetles cause considerable mortality (Perry,1951; Moreno,1954; Thatcher,1960; Rudinsky,1961, 1962).

Study techniques. Dixon and Osgood (1961) reported that various methods of rearing D. frontalis, under artificial conditions, were tried with little success. The methods tried were the following: "(1) causing mechanical injury to standing trees (to induce attack for later observations); (2) caging infested bark on standing trees; (3) caging infested bolts on trees; (4) caging infested bark and phloem with uninfested bolts (ends waxed); (5) caging infested bark and phloem with uninfested scorched bolts; (6) caging infested bark and phloem with uninfested

mechanically injured bolts; (7) caging infested bark and phloem with uninfested bolts treated with sulfuric or acetic acid; and (8) caging infested bark on uninfested bolts. It appeared that the high moisture contents of the wood and inner bark of the bolts were unfavorable for the development of the early larval stages."

Fronk (1947) found the sandwich technique to be superior to any log caging method for direct observation of larval growth and instar determination. The insects were transferred to fresh bark sandwiches, when the phloem turned brown. Small niches which he cut in the wood provided a receptacle for the insect.

Clark (1964),[8] reported success in rearing D. frontalis in logs placed in 20 gallon steel cans. He also reared them on artificial diets. Stark[7] also successfully reared Dendroctonus sp. from egg to adult in a homogenate mixture of ground phloem tissue with some fungicide added.

Materials and Methods

Study areas. The same bark beetle epizootics used for the D. valens study described in Section I of this dissertation were also used for the study of D. frontalis. One was in a mountainous region near the town of Nicolas Romero in the state of Mexico while the other was on a flat lands plantation near the town of Puebla in the state of Puebla. Both of the stands contained about 90% Pinus

leiophylla with the rest of the trees being P. montezumae and P. patula. The spread and decline of the epizootic were observed in both areas during the course of this study.

Laboratory temperature studies. Various methods of rearing D. frontalis were tested, including the glass sandwiches successfully used for D. valens. Freshly killed bark free of insects, infested bark with insects in situ, a homogenate mixture of bark and wood, and a bark sawdust mixture in the glass sandwich were tested without success.

The beetles died in the homogenate and sawdust mixture due to excessive fungus growth, inability to maintain a sufficient bodyhold for feeding, or other environmental conditions. Using bark peeled from trees with the eggs and larvae in situ was superior for rearing with the sandwich technique. The larvae, however, could not be observed through the glass since they bored into the inner phloem for food.

In the laboratory the beetles were reared successfully in uninfested, freshly killed logs which were heavily waxed at both ends and on all bark openings to reduce moisture loss. The beetles which attacked the freshly killed logs emerged from field infested logs placed in the same room.

I noted a wide variation in beetle development when sampling the logs. These variations in instar and stage development usually occurred in different logs, but were

also noted in the same log. The developmental variation may be explained by a combination of bark thickness, texture, structure, protein content, intraspecific competition, or other variations.

Mites were observed in large numbers, in phoresy, on the adult and larval bodies in all the sandwiches and logs. Their numbers were reduced by changing the sandwiches, but they quickly increased thereafter. Their effect upon the larvae and adults is unknown, but they possibly hindered the movements and feeding of the beetles.

The studies were conducted in three rooms. One incubator room was maintained at constant temperatures of 15 C and another at 26 C to study responses of all stages of the insects to temperature differences. The third room was used to maintain the logs at 14 to 15 C after they were brought in from the field, and also served as an infestation chamber for initial attacks by the beetles. Following the initial attack, the logs were transferred to the constant temperature rooms.

The temperature in the 15 C room remained constant except for two days when it varied, plus or minus one to two degrees, from 15 C. The temperature in the 26 C room always was regulated within one degree plus or minus of that temperature. Preliminary tests showed that in all portions of the 26 C room, the temperature variation did not exceed 1 C.

Infested Pinus leiophylla trees were cut into logs about one meter in length to serve as a source of beetle infestation for the temperature studies. These logs were trucked to the laboratory and held in underground rooms at 14 to 15 C until beetle emergence occurred about one week later. They were then used for infestation purposes in these rooms. Noninfested bolts from the same forest area also were cut and the ends coated with paraffin wax to prevent moisture loss and were placed in the infestation rooms three at a time for a 48 hour infestation period in the 15 C room and for 24 hours in the 26 C rearing room.

After the infestation period, the beetles on the surface of the bark were brushed off and the bolts were transferred to the developmental rooms for further observations.

Bark inspections were made every other day, beginning the day after attack, to follow the life cycles from the time of adult entrance through the development of offspring to emergence of new adults. The bark sampling method employed consisted merely of removing enough bark to obtain the desired number of insects. Each bark sample was examined and discarded on each sampling day. In the beginning, a total of five to ten families constituted a sample but due to large numbers of insects this was later reduced to five families and finally to 100 insects.

Field temperature studies. To record temperatures

for this study, the same location, tree, method, and materials used for the D. valens study were employed in the study of D. frontalis. However, to record subcortical temperatures, the thermocouple junction was inserted into the galleries of D. frontalis about one meter above the ground level instead of at the ground level. Temperatures were recorded on five days, four of which were on the same dates as taken for the D. valens study (January 21-22, 1964; May 14-15, 1964) (Figs. 10-12, App. 10-12). The additional temperature recording was on January 23, 1964 (Fig. 11, App. 11) where the thermocouple junctions were sealed in place with pitch to prevent air movement.

Laboratory Results

Sex ratio. The same method to separate the sexes of D. valens was used for D. frontalis. The insects were collected as they emerged from field infested logs that were brought into the laboratory during both the wet and dry seasons. The insects were preserved in 90% alcohol in jars and random groups of 50 adults constituted a sample. The following table represents the results of the sex determination:

Sex ratio results of adults Dendroctonus frontalis

Sample No.	Females		Males	
	No.	%	No.	%
1	30	60	20	40
2	30	60	20	40
3	31	62	19	38
Total	91	60	59	40

The sex ratio of these samples was 60:40 females over males. The species is typically monogamous, but several females were observed in logs, both in laboratory and field logs, without males. Some of these lone females abandoned the gallery while others remained and oviposited. Some males were probably killed in resin flow, probably after copulation, and the females continued the gallery alone.

Larval instars. The same method of collecting, preserving, and measuring the larvae that was used for D. valens also was used for D. frontalis. The following table gives the results of the measurements shown in four groups and compares the mean diameters obtained in this experiment with those obtained by Fronk (1947).

Larval instar determination of Dendroctonus frontalis

Instar & Number Examined	Diameter in mm	Standard Deviation	Mean	Fronk Mean
I-100	0.300-0.350	0.250	0.325	0.317
II-100	0.380-0.500	0.360	0.463	0.429
III-100	0.550-0.700	0.220	0.644	0.616
IV-200	0.720-1.100	0.180	0.857	0.851

These measurements were used to identify larval instars in both the preliminary sandwich technique and the mass log rearing technique. Exuviae and white head capsules of newly moulted larvae were counted during the sandwich technique which confirmed the separation of the

four larval instar groups.

Fronk (1947) determined the number of larval instars of D. frontalis by measuring the head capsule or larvae collected near Chase City, Virginia. The above table shows his mean head capsule measurements, which were about the same for the first and fourth instar and slightly smaller for the second and third instar, when compared with the larval mean head capsule from insects collected in Mexico.

Development at 15 and 26 C. The insects were reared in the laboratory in logs one meter long. These logs were infested by exposing them to a heavy population of beetles for 48 hours for the 15 C experiment and for 24 hours for the 26 C experiment. After exposure each set of logs was stored in a separate laboratory. The temperature was recorded once daily. Observations of beetle activity and gallery development were made on alternate days. To do this, sections of bark had to be removed to expose the galleries. The results are presented in Tables 3-7 and in Figures 14 and 15.

The number of family galleries (those containing one male and female parent adult) examined each time decreased on successive dates, due to the increasing number of insects found in the sample. Finally, only 100 insects were counted in each sample (Tables 3,5).

The length of adult galleries was measured and averaged. Some parent adults constructed short oviposition

galleries but emerged shortly afterwards, possibly due to absence of mates, unsuitable host material, or intra-specific competition. The longest average length of completed adult galleries at 15 C was 57.4 cm while at 26 C it was 56.2 cm (Tables 3,5). This average between 1.33 and 1.43 cm per day, a figure obtained by dividing the longest average gallery length by the number of days after attack. Most of the adults remained in the gallery where they died after oviposition.

At 15 C, the oviposition period began two days later than it did at 26 C. The peak of egg abundance was two days earlier at 15 C than at 26 C (Table 7). When the peak of egg production was reached, the parent galleries were approximately one-third completed (Tables 3,5).

Since the female oviposited for a month or more, the data were recorded as the minimum developmental time for all instars and stages. This minimum developmental time was based on the number of days it took for the first insect observed in the samples to moult to the next instar or stage. This is not necessarily the actual minimum developmental time as would be determined by observing the length of time individual live beetles spend in a particular instar or stage. The duration of any instar or stage was also recorded and was based on the total number of days the instar or stage was observed in the samples. The data also shows the peak of abundance for most of the

instars and stages. The total larval period extended to 123 days after the initial attack at 15 C and to 107 days at 26 C, or a difference of 16 days.

At 15 C, the first larvae were observed on the 17th day after attack. At 26 C, the first larvae were observed on the 11th day after attack. The peaks of abundance for different larval instars occurred about the same time at both temperatures (Table 7). The fourth instar required twice as long to develop at 15 C as it did at 26 C (Table 7). Fourth instar larvae were found during a period of 88 days at 15 C and for 68 days at 26 C. This 20 day difference was based upon the first and last larva in the fourth instar that was found in the samples of each brood. This increasing separation of developmental time can be noticed in Figure 14 as the development of the insects progressed.

The larvae feed from the inner bark (Fig. 22) to the outer bark where each one builds a pupal chamber and pupates within it (Fig. 23). The insect remains in the pupal chamber through the callow adult stage. The callow adult stage was represented by the newly moulted adults which were white upon transforming and slowly darkened to a light brown and finally to a dark brown color. The adults were dark brown to black in color and were collected from the outer bark region. These adults were engaged in enlarging the pupal chamber and perforating individual exit galleries through the bark.

The minimum developmental time for pupae, callow adults, and adults to remain in the log could not be determined at 26 C because all of these stages plus the exit holes were first found on the same date (Tables 6,7). Natural variation in the development of the beetle population in the different logs samples caused this difference in the recorded data.

The peaks of abundance for pupae, callow adults, and adults occurred about 30 days later at 15 C than at 26 C. At 26 C, pupae and adults were present in the logs for about the same length of time. This period was significantly longer than that for any other stage or larval except the fourth instar (Table 7).

The average life span of the brood adults from the population obtained in the laboratory samples was approximately 87 days based on the number of days that live adults were found, both in the logs in which they developed and in the logs they attacked. This also included three days between emergence from logs and the attack on new trees. With this system of measuring, the actual duration of the adult stage was observed for a much longer period. During an epizootic the number of days between emergence and attack was ascertained in the field for a few adults which were observed to attack new trees on the day of emergence.

The exit holes were counted as emerged adults since each adult generally makes its own exit gallery through the

bark. Consequently, new exit holes were made until adult emergence was completed. The generation was completed in 125 and 107 days after attack at 15 and 26 C, respectively.

The first emergence of adults was observed 81 and 53 days after attack at 15 and 26 C, a difference of about 30 days. A comparable developmental difference was also observed in the peak abundance at these two temperatures in the pupae, callow adults, and adults. The 11 C temperature difference between 15 and 26 C equaled about three developmental days for each degree Celsius between 15 and 26 C (Tables 3-7).

Figure 15 represents a developmental time graph for the duration of the various instars and stages based on the first and last insect of the brood to moult in the log samples. The dotted lines represent the minimum developmental time for the first insect observed to moult from the samples. The dotted and solid line together represent the total number of days for the duration of a stage or instar that was observed in the samples. This graphic method of presenting results was taken from Tables 3-6.

Also, Figure 14 was taken from Tables 3-6 and demonstrates the length of development in days for different stages and instars with respect to minimum developmental time. The data were based on the first insect observed to moult from the samples. The difference in development at 15 and 26 C gradually increased until a 20 day difference

was observed in the time for the callow adult stage to be completed (Fig. 14).

The difference in development was due not only to temperature differences but probably also to the physiological condition of the host tree. The irregularities in seasonal occurrence or peaks of abundance of the various instars or stages might demonstrate some evidence of host physiological differences. In Figure 21 the larval galleries can be observed to be of an irregular circular pattern. Other larval galleries were observed to have an elongated gallery which might suggest exploratory feeding to locate proper food. The circular galleries may demonstrate sufficient food or nutrients was found there and larval gallery extension was not necessary. This difference in larval gallery form was not associated with height of tree, size of tree, temperature, site, associated insects, or thickness of bark. However, each type of gallery was associated with one tree. Both types were not found in the same tree and the circular larval gallery was the most common and can probably be considered the normal larval gallery.

Field Results

Attack habits and evidence of attack. D. frontalis, usually, first attacks the middle section of the tree trunk. Later attacks extend upward until a minimum stem

size of approximately five inches is reached. Bases of limbs are often the point of attack. Finally, the attack extends down to the ground line. The time involved to completely infest a tree varies considerably, depending upon the size of the beetle population in the vicinity of the tree. During epizootics, trees were attacked in mass and the time it took to completely infest a single tree varied from one to two hours through one to several days. Once a tree was saturated with beetles, new attacks stopped.

Density of attack varied notably between different species of host trees, and within vigorous conspecific hosts. During enzootic conditions host trees were repeatly attacked over different sections of the trunk and such attacks could extend over several months. Probably the offspring from the initial attackers developed into adults and attacked the same host tree as their parents.

The new colonizing adults usually mated on the bark surface while others were observed mating shortly after perforating the bark. The female was observed entering the tree and boring through the bark or phloem to the cambial region with the male following. She then made a sinuous gallery upward along the cambial region, etching both the inner phloem and the outer xylem layers. The gallery was continuously lengthened by the female with the male usually following about 5 cm behind. The gallery may also cross other galleries of the same or other species

(Fig. 21). The male pushed the resin and frass (wood chips and excrement pellets) out of the log through the opening. The female deposited eggs in marginal niches which she prepared, alternately, along both sides of the gallery (Fig. 20). As the gallery was enlarged past the first oviposition niche, the male used the frass to plug the gallery to the rear and pack the eggs in their niches (Fig. 19,21). The male also made ventilation holes spaced along the gallery.

The adults generally died in the galleries. However, some parent adults were observed emerging from the trees after they had deposited eggs. Competition or an undesirable location in the bark could have forced them out. These adults may attack the same tree a second time if it dies slowly or may attack another tree. Many males, especially during the initial attack, succumbed in the resin. Females were observed laying eggs and continuing the gallery alone. Some females were observed alone, without having oviposited, in an enlarged gallery of two inches or more in length which might have been a nuptial chamber. Other lone females, in galleries having nuptial chambers, were observed ovipositing along newly formed galleries. These observations were in trees that had been attacked several weeks previously and the nuptial chambers are not normal for D. frontalis. The females may have formed the chambers while waiting for a male to enter.

The larvae pass through four instars during their

development in the bark. The larval gallery was first bored into the inner bark and finally into the outer bark. Each larva maintained a separate distinct sinuous gallery (Fig. 22). The course of the gallery was changed as it approached other larval galleries. The larva in the last instar enlarged the end of the gallery to form a pupal cell (Fig. 23). It then became a quiescent prepupa for one or two days and then transformed to the pupal stage. After about a week the pupae transferred to the callow adult stage. The callow adults remained quiescent in the pupal cells for about a week. Each new adult finally bored an exit gallery through the bark and emerged. These adults remained on the bark surface for a few hours expanding their wings before taking flight.

The emergence of beetles continued for one to two months. The length of the emergence period depended upon the season of the year. In field and laboratory observations the rate of emergence increased rapidly at first but later lessened gradually. Emergence reached its peak between 20 and 30 days after the first beetle emerged and was completed in 30 to 60 days after the peak.

Emerging beetles commonly flew to trees a few feet away during the epizootics as attacks to new trees were observed around the perimeter of the epizootics. The beetles flew singly or in swarm-like groups near sundown. The two species, D. frontalis and D. valens, also were

observed taking flight together in swarms. They were seen migrating to a nearby group of trees which they attacked simultaneously. It is possible that mass migrations of these beetles might descent upon more distant trees.

All stages were observed throughout the year. The great overlapping of different stages in the same tree and the same group of trees caused difficulty in determining the number of generations per year. However, it was estimated that about five generations occur annually. This was based on fairly conspicuous advances in the spread of the epizootics at Nicolas Romero and Puebla, where groups of trees were attacked at periodic intervals.

The first evidence of attack was the frass that was extruded from small entrance holes that perforated the bark and, finally, the flow of resin from the entrance hole. The resin solidified upon leaving the tree and formed a "pitch-tube." The pitch tube varied from whitish to reddish in color depending upon the color of the bark of the host tree.

The resin flow is a form of "bleeding" due to sap pressure. The extent of flow may vary with the quantity stored or produced by different trees. The copious resin flow during the early stages of heavy attack and for longer periods during light attacks offers some resistance against the beetles. The resin flow caused by the first beetles that attacked near the middle of the trunk

appeared to attrack more beetles, commonly in masses, within one or two days. This was probably due to a strong odor of resin. Following the initial attack, the resin exuded from the entrance holes and ran down the tree trunk in long strands up to two meters long. Also the ground and bark were often littered by drops of resin. Pitch tubes of resin finally hardened when the resin flow ceased (Figs. 17, 19). Both female and male beetles were sometimes suffocated in the resin flow (Fig. 19).

During the course of attacks by additional beetles, the resin flow per gallery was reduced. Later attacks by adult beetles produced only a small pitch discharge at each entrance. As the resin flow subsided new beetle attacks continued, first upward into the crown then into the basal portions of branches and downward to the ground line. The discharge was finally composed of more frass than resin. Ips bonanseai and Ips cribricollis, which usually attacked later, produced very little resin flow.

The resin flow from the more vigorous trees temporarily resisted the infestation but the beetles continued to attack them until the resin flow ceased. Such trees supported a large population of beetles but the heavy resin flow killed many of them during the attack. Certain vigorous specimens of Pinus leiophylla, P. montezuma, and P. patula did resist the attacks longer. In two epizootics, P. patula was not attacked when growing in

mixture with the other species. Other observations on P. patula showed that the trees were attacked by a few beetles which were killed by the flow of pitch. P. leiophylla was the preferred host.

When the bark was removed, the sinuous adult galleries and small larval galleries partially hidden in the phloem were observed (Fig. 21). The larval galleries consisted of two types. One was irregular or more or less circular in form (Fig. 21) where the larvae remained in the same location near the adult gallery and fed in a circular fashion. The other was an elongated sinuous larval gallery leading away from the parent gallery. It enlarged in diameter as the growing larvae extended it. Each type of larval gallery was restricted to a specific tree, which may suggest the beetle has requirements for certain moisture or nutrient conditions.

From the start of larval development through emergence of the young adults, the foliage changed in color as the trees died. The stage of development of the brood could be estimated from the color of the foliage as follows (roman numerals indicate the larval instar involved):

Green (normal	- New Adults, Eggs, Larvae I
Faded green, yellowish	- Larvae I, II
Yellow	- Larvae I, II, III
Yellow red	- Larvae II, III, IV
Brown red	- Larvae IV, Pupae, Adults
Dark brown red	- Pupae, Adults
Dark red to defoliation	- Secondary insects only

By the time the needles fell, the trees were extensively invaded by fungi and secondary insects. Most of the secondary insects such as ambrosia and cerambycid beetles began entering the tree during and after the yellow foliage stage. Only Ips, when epizootic, entered the main tree trunk as early as the green foliage stage, one to two days after the initial attack by D. frontalis. Usually, Ips entered later and only in the crown portion of the trunk.

Trees, 12 inches in DBH, that were killed in November 1961 were broken by the wind, 6 to 10 feet above the ground one to one and a half years after attack. Many of the small branches in the crown had fallen from the trees that were still standing. The wood of these trees was deteriorated by decay causing fungi and was of a rotten texture.

Population fluctuations. Under epizootic conditions, in Central Mexico, D. frontalis kills healthy pine trees in large numbers and is considered a primary bark beetle. When the beetles exist in low numbers, such as between epizootics, they kill only scattered weakened trees in the forest and are then more secondary in nature.

The concentration of attack on a single tree may vary with the individual tree or species of tree. For example, the average attack on Pinus leiophylla showed 14 pitch tubes per square foot of bark surface. Samples from

presumably more resistant trees of the same species averaged up to 30 pitch tubes per square foot of bark surface with many of the beetles killed by the pitch. Nevertheless, the number of beetles in the developed brood was the same for both because many of the initial beetles were killed and only the late attackers survived to produce any offspring, as evidenced by the equal number of exit holes.

Approximately 15 epizootics were observed over a period of two and one half years. Most of these areas were in about the middle stages of an epizootic and covered several acres. Single attacked trees also were observed. The most obvious factors that might be conducive to attack by D. frontalis is mechanical damage to the trees by man, from collection of firewood and resin and from fire damage. Many unchecked forest fires were observed, which usually destroyed the duff, grass, and small trees up to two meters high but also damaged the base of larger trees. Erosion following the fires further weakened some of the trees. Beetle epizootics were observed in the areas usually a year or more after the fire. Drought and rainfall deficiencies were also reported to have occurred in many of the epizootic areas.[3,4]

The injurious conditions cited above were also observed in attacks on lone trees and in small infestations. I also observed attacks on large old overmature trees and large trees that showed mechanical damage by natural causes

such as wind and lightning in these small infestations. All these conditions were observed in Central Mexico and any one or a combination of them could have been responsible for the beginning and promotion of the epizootics. Similar conditions were observed in enzootics, localized to certain regions of the forest. Probably when these conditions were severe enough, individually or in combination, they further weaken the tree and attract the beetles.

The growth of an epizootic begins slowly, but with the proper combination of host and weather conditions, the beetle population increased rapidly. Epizootics almost exploded in size as new groups of trees were attacked around the previously attacked trees. When the population became large enough to attack the trees en masse, the normal weather and host conditions seemed to have little effect upon the growth rate of the epizootic.

The epizootics observed in Central Mexico expanded rapidly over the first and second year, covering approximately 30 to 100 acres. However, attacked trees, occurring singly or in small groups of three to seven in the forest also were observed which did not increase to epizootic conditions. During the second and third year of the epizootic, a decline was observed in the population. Other Ips bark beetles plus parasitic and predatious insects were observed to fluctuate in abundance during the epizootic. A general increase of these associated insects occurred which,

presumably, eventually aided in the resultant decline of both D. frontalis and themselves. Initially, Ips. sp. were observed to completely occupy their normal bark habitat in the crown. Eventually they occupied the entire tree trunk as their population increased. The competition with Ips is believed to be the primary factor in the decline of the D. frontalis epizootic at Puebla. This was substantiated by both field and laboratory results. The population decline is further discussed in Section III under Biological Control Notes.

Temperature studies. Detailed temperature studies were made in the environment of D. frontalis on five clear sunny days (Figs. 11-13, App. 10-12), three in January and two in May. The dates were the same as in the D. valens study except for the additional recording on January 23. Temperatures were recorded in similar situations, except in the case of the four subcortical temperatures which were taken on the tree trunk one meter above the ground, instead of at the ground level.

As in the D. valens study, subcortical temperatures closely followed the air temperature, fluctuated in relation to each other in response to the same environmental factors, and did not drop quite as low at night (3 C higher). On January 21-23, the maximum subcortical temperature recorded during the day was 26.1 C, while the minimum at night was 9.4 C. In May, the maximum and minimum

subcortical temperatures were 32.2 and 5.5 C, respectively. The low 5.5 C temperature recorded in the cold period in May should be a frequent occurrence during the typically cool nights that occur during all seasons of the year on the high mountainous plateau of Central Mexico. The 32.2 C temperature recorded in May was near the high lethal point for D. frontalis since all stages of this insect died in the laboratory logs at constant temperatures of 35 C in a few days.

The temperature recordings for Figure 12, where the thermocouple junctions were sealed in place, showed about the same fluctuations as the recordings on the other dates where the probe gallery was exposed to the air.

Unlike D. valens, which has most of its galleries underground where they are insulated against wide temperature fluctuations, D. frontalis was exposed to much wider daily subcortical temperature variations since it lives in the trunk above ground level. In view of the wider temperature fluctuations in the beetle's niche, the development rate of D. frontalis also must have fluctuated more than D. valens. The range of subcortical temperatures recorded, however, permits year-round development. All stages were found throughout the year. The cool nights probably only retard growth temporarily.

One generation probably extended over two to three months at May temperatures as compared with a possible

three to four months at January temperatures. Based on the information obtained during the laboratory rearings and field observations, D. frontalis probably completes about five generations a year in Central Mexico.

Summary

The bark beetle Dendroctonus frontalis Zimm. is a primary and important forest insect pest in Mexico. This species has caused the greatest loss of timber by any one insect in Mexico. In the Southeastern United States and Honduras it also is considered a forest insect pest of primary importance.

The materials and methods used are presented for the field and laboratory temperature studies. No successful laboratory rearing methods were found, such as the glass and bark "sandwich" method used for D. valens. Logs freshly cut from live trees were exposed to D. frontalis attack and the beetle development was then followed by opening and sampling new bark from the infested logs on alternate days.

The evidence and habits of attack were observed in the field and at the site of various epizootics by direct examination of bark samples. All stages of the beetles were found throughout the year in Central Mexico. The number of generations per year was estimated to be about five. Foliage color on infested trees was correlated

with the development of the egg, larval, pupal, and adult stages. When the foliage was dark red brown in color the beetles were emerging.

D. frontalis was usually found in small epizootics of 30 to 100 acres. The initial period of an epizootic began slowly but the beetle population then increased rapidly, especially in the first and second year. During the second and third year, the population declined and in one intensively studied epizootic the cause of the decline of D. frontalis was believed to be due primarily to interspecific competition with secondary bark beetles of the genus Ips.

Two types of weather occur in Central Mexico, the dry season from November to May and the set season from June to October. Development is retarded in the dry cool months of December to February. Field temperature recordings were presented showing the daily fluctuations in the environmental niche (gallery) of D. frontalis.

Under the partial shade of the forest canopy intermittent sunlight and shadows occur on the tree trunk throughout the day. Subcortical temperatures on different sides of the tree varied somewhat erratically in relation to each other, but they followed the normal daily rise and fall of the air temperature fairly closely. The maximum and minimum temperatures were not high or low enough to cause mortality but they might result in different rates

of development in different locations.

Four larval instars and the adult sex ratio of 60:40 females to males were determined from field and laboratory collected insects.

Other laboratory research consisted of rearing D. frontalis at temperatures of 15 and 26 C. The insect's development was followed from egg, larvae, pupae, callow adult, and finally to the mature adult stage.

The adult galleries were measured and the average completed length was close to 56.0 cm at both temperatures. In view of the time required to construct the galleries, construction must have proceeded at the rate of about 1.3 cm per day. Oviposition began two days later at 15 C than it did at 26 C. Eggs were most abundant in the logs when the galleries were about one-third completed. The larval period extended to 123 days after attack at 15 C and to 107 days at 26 C. The fourth larval instar completed development 20 days later at 15 C than at 26 C. A difference of 30 days between the successive peaks of abundance at 15 C and 26 C also were observed for the pupal, callow adult, and adult stages. The 30 day difference was also observed when the first emergence of new adults appeared 81 days after attack at 15 C and 53 days after attack at 26 C. All the beetles emerged and the generation was completed in 125 and 107 days after attack at 15 and 26 C respectively. The brood adults were estimated to have an

average life span of approximately 87 days based on the population in the samples.

Conclusions

All stages were found throughout the year in Central Mexico and a great overlapping occurred within offspring of the same family, broods of the same tree, and generations of the same epizootic. However, the biotic potential of this insect is very high and a population increase can occur in one year covering hundreds to millions of acres, as occurred during an epizootic in Honduras between 1962-5.

Field observations showed that the epizootics begin in a few weakened trees and progress to healthy trees after the population becomes very abundant. The decline of an epizootic was observed to be caused by competition from secondary bark beetles of the genus Ips. This interspecific competition by Ips. sp. may play a much more important role in epizootic declines of D. frontalis and perhaps other Dendroctonus sp. than previously known.

In Central Mexico there probably are about five generations a year as observed in the field and estimated from the temperature studies. About a 20 C air and sub-cortical temperature fluctuation occurred during the day. The temperatures fluctuated due to the sun rays that were intermittently intercepted by the forests canopy. No mortality due to cold temperature probably occurs in Central

Mexico where the bark beetles are distributed, but development is probably stopped temporarily during the cold early morning hours before sunrise.

The difference in development between 15 and 26 C was about one month for the first of the broods to complete development. The females oviposit eggs for over 30 days whereas beetle emergence lasted about two months. A 30 day development period showed up in the difference between peaks of abundance of different stages. This represented about a three day developmental difference for each stage per degree Celsius between 15 and 26 C.

Developmental difference was believed associated with the physiological condition of the host tree as observed by two different types of larval galleries. This development difference was demonstrated where the logs or log groups were changed for sampling. One type of larval gallery always was found within the same tree. The type of larval gallery possibly was related to food condition of the host. It was not related to height of the tree, size of the tree, temperature, site, associated insects, or thickness of bark. The circular larval gallery was the most common.

S E C T I O N I I I

THE CONTROL OF *Dendroctonus frontalis* (= *mexicanus*) Zimm. IN CENTRAL MEXICO (Coleoptera:Scolytidae); INCLUDING NOTES ON CHEMICAL CONTROL OF ASSOCIATED *Ips bonanseai*, *Ips cribricollis*, PARASITES, AND CLERID PREDATORS.

Introduction

The economic and cultural situation in Mexico has resulted in a high value on, and greater demand for timber for paper making, and is bringing about the need for control of bark beetle epizootics which cause destruction to the pine forests.[3] Dendroctonus sp. alone account for approximately 80% of the forest tree mortality that is caused by insects in Mexico (Hartig, 1954). Effective control or eradication of bark beetle epizootics is necessary to prevent additional spread and subsequent destruction of the forests.

Insecticidal control of Dendroctonus frontalis has been tested in the United States, largely in field experiments. Since environmental conditions in Central Mexico are quite different, it was deemed necessary to conduct further experiments in the laboratory and field. Also, it was thought that the speed and efficiency of chemical control would far surpass the slow mechanical control operations now generally employed.

Pesticide tests on D. frontalis and Ips sp. were aimed at determining the effectiveness of chemicals for possible control or eradication of epizootics. One insecticide was selected for testing from each of four groups of chemicals; a chlorinated hydrocarbon, and organophosphate, a bromide fumigant, and a carbamate.

The mechanical control and salvage operations against D. frontalis and Ips sp. were observed in the field at two different epizootics where control procedures were modified.

The biological control studies of D. frontalis and Ips sp. were limited to laboratory and field observations. The association of the parasites, hyperparasites, and predators on D. frontalis and Ips sp., and their influence on them was not completely determined.

Analysis of Literature

Remedial chemical control. The literature analysis of chemical control of several Dendroctonus sp. will be confined to remedial control only.

Different investigators used different methods for mixing the insecticides and a comparison of per cent of the actual toxicant used was not always possible because of insufficient information on the percentage of active ingredients in the commercial products used.

Stopping bark beetle epizootics is vital to successful forestry, since bark beetles destroy more than four billion board feet of timber annually in the United States (U. S. Forest Service,1958). Lyon (1965) reported that insecticides are indispensable in remedial control of bark beetles.

The insecticides are usually applied liberally as emulsions and suspensions over the bark surface to standing

or felled trees, until a "run-off" point is reached. The insecticidal emulsion sprays penetrate to the inner bark surface, killing all stages of the beetles; and it also remains as a residual deposit on the bark surface to kill the emerging adult insects. These suspensions do not penetrate but remain as a residual deposit on the bark surface only. Chemical control is an expensive, but effective method for remedial control of bark beetles which greatly reduces the amount of time and work expended in control operations (Lyon,1965).

Salman (1938) tested insecticides composed to crude flake naphthalene, orthodichlorobenzene, paradichlorobenzene, and beta-naphthol in penetrating oil sprays on D. pseudotsugae beetles. Average mortalities ranged from 18.0 to 80.4% in his series of experiments. Best results were obtained with crude flake naphthalene at the rate of 3/4 lb. of the commercial product per gallon of an emulsion, made up of 20% fuel oil and 80% water applied during the summer on dry bark. This resulted in destruction of the brood and prevention of further attacks, but the host tree usually were not saved because the beetles had already effectively girdled them and destroyed the cambial layer.

Orthodichlorobenzene produced more than 90% mortalities to D. frontalis, D. ponderosa (= monticolae), D. obesus (= engelmanni), and D. pseudotsugae when sprayed on felled trees with diesel oil at about 2% concentration

(Gibson,1943; 1957; Massey and Wygant,1954; Kinghorn,1955; Ostmark and Massey,1960).

Evenden et al. (1943) recommended a penetrating spray composed of four parts diesel oil to one part orthodichlorobenzene which yielded satisfactory results on D. ponderosa (= monticolae).

During World War II, new residual organic insecticides such as DDT and other chlorinated hydrocarbons were developed and used against bark beetles (Lyon,1965). Hall (1946) experimented with penetrating sprays of five and 10% DDT in kerosene. He obtained 74 to 98% brood mortalities of D. brevicomis beetles. Oil mixtures of 2-4% DDT concentration resulted in over 90% mortalities to D. ponderosa (= monticolae) and D. obesus (= engelmanni), but these low concentrations were recommended as a preventive measure, and not as a remedy (Massy and Wygant,1954; Kinghorn,1955).

The chlorinated hydrocarbons such as aldrin, chlordane, DDT, dieldrin, heptachlor, and lindane were tested by Kinghorn (1955) against D. ponderosa (= monticolae). Concentrations of all the insecticides used were 3.2 lbs. of the commercial product in a five gallon emulsion of 20% diesel oil and 80% water. The insecticides listed from most effective to least effective were respectively aldrin, helptachlor, lindane, dieldrin, chlordane, and DDT.

Lyon (1965) studied DDT, dieldrin, dinitrocresol, endrin, heptachlor, and lindane for their residual toxicity

and their penetration of the bark when mixed with xylene in controlling Ips confusus, D. brevicomis, and D. ponderosa (= monticolae). The insecticide dosages were measured in milligrams per square foot of bark surface for the sprays on penetration and residual effects. Lindane was the most toxic; dieldrin and endrin showed good promise for effective control; dinitrocresol, heptachlor, and DDT were less toxic.

BHC sprays applied against D. frontalis in the southeastern United States were effective at concentrations between 0.25 to 1.0% gamma isomer content in diesel oil or No. 2 fuel oil, when applied liberally to the bark surface. The BHC applied as an emulsion in oil acts as a contact, stomach, and residual insecticide. The oil penetrated the bark, carrying the insecticide with it, and killed on contact all stages of the beetles. In areas of thick bark, such as the lower bole of the tree, the insecticides acted more as a residual, and was contacted or ingested as emergent galleries were constructed by young adults (Speers et al., 1955; MacCambridge and Rossoll, 1957; Kowal and Rossoll, 1959; Kowal, 1960; Thatcher, 1960; Dixon and Osgood, 1961; Moreno, 1962; Ketcham and Bennett, 1964; Schwerdtfeger, 1964; Lyon, 1965).

In Mexico, Moreno (1962), tested a 12% gamma isomer of BHC wettable powder diluted by water to a 1% gamma isomer spray on D. frontalis. Freshly felled trees were sprayed to the point of "run-off." The epizootics were not controlled

and repeated applications were necessary to achieve control.

Ketcham and Bennett (1964) recommended testing at 0.5% gamma isomer of BHC spray, dissolved in diesel oil on felled trees for aid in control of a large D. frontalis epizootic in Honduras. Mortalities were 97% on the upper surface to 43% on the sides of the felled trees, using the 0.5% concentration, as reported by Schwerdtfeger (1964). Schwerdtfeger (1964) recommended 1% gamma isomer BHC spray, dissolved in water, be applied to felled trees in Honduras to obviate the cost of the diesel oil in the spray control project. The results of Schwerdtfeger's recommendations, as reported by Haider,[11] showed that 1% BHC gamma isomer in water alone produced lower mortalities than 0.5% BHC gamma isomer in diesel fuel. It was also recommended that these mixtures be applied from airplanes, three times at ten day intervals. Haider[11] reported the airplane tests were not successful. Fox, et al. (1964) reported that in a period of eighteen months, from the beginning of the epizootic fifteen successive generations of beetles destroyed 11,000,000 trees, in an area 112 X 118 miles. He estimated that during the 18th month period, about 193,000 trees were attacked daily. He concluded that the human and economic resources available in Honduras were not sufficient to establish a successful control program. Since the epizootic was for the most part located in inaccessible areas control measures were more difficult to establish.

Coyne[10] in 1966 reported that the epizootic collapsed after about three years, in mid 1965, due to natural causes. Lindane at a 1.5% or higher concentration in diesel oil has produced 90% mortalities, acting on D. brevicomis as a contact, stomach, or residual insecticide (Lyon and Wickman, 1960; Wickman and Lyon, 1962). Ostmark and Massey (1960) recommended a 1% lindane mixture in diesel oil as effective control for D. frontalis.

In recent years in the United States, ethylene dibromide in diesel oil on felled trees has been widely used as a penetrating spray at about a 2% concentration against D. brevicomis, D. frontalis, D. obesus (= engelmanni), and D. ponderosa (= monticolae) on felled trees. Mortalities of above 90% have been recorded (Downing, 1954; Massey and Wygant, 1954; Kinghorn, 1955; Gibson, 1957; Stevens, 1957, 1959; Wygant, 1959; Sharp and Stevens, 1962; Ostmark and Massey, 1960).

Topical application. Few laboratory studies have been published on contact toxicity by topical applicators to Dendroctonus bark beetles.

Moore (1957) tested contact toxicity of insecticides to bark beetles by topical application. The insecticides, from greatest to least toxicity to D. brevicomis, at LD_{50} range, were isodrin, lindane, DDT, and toxaphene. All insecticides in the same order were more toxic at LD_{50} and LD_{90} range to Ips confusus than to D. brevicomis. A

significantly steeper probit slope was obtained from isodrin in comparison to the other insecticides.

Lyon (1959) conducted experiments similar to Moore's on D. brevicomis and D. ponderosa (= monticolae). The beetles were given a volumetric dose proportional to their body weight. Insecticides, from greatest to least relative toxicity at 95% confidence levels were endrin, isodrin, EPN, lindane, dieldrin, heptachlor, dinitrocresol, and DDT for D. brevicomis. Both endrin and isodrin were 11 times more toxic than DDT. The insecticides, from greatest to least relative toxicity for D. ponderosa (= monticolae) at 95% confidence levels, were lindane, isodrin, EPN, endrin, dieldrin, heptachlor, dinitrocresol, and DDT respectively. The toxicity of lindane in this test was 21 times greater than that of DDT.

Rudinsky and Terriere (1959) conducted tunnel spray applications of 10 insecticides in acetone solutions to determine the contact toxicity to D. pseudotsugae. At LD_{50}, with 95% confidence levels, the relative toxicity from the most to the least toxic insecticide was as follows: lindane, Thiodan, isodrin, endrin, carbaryl, heptachlor, aldrin, dieldrin, DDT, and chlordane. At LD_{90}, with 95% confidence levels, the most to least relative toxic insecticides were Thiodan, endrin, lindane, isodrin, carbaryl, aldrin, heptachlor, dieldrin, DDT, and chlordane. All the insecticides were more toxic to the male D. pseudotsugae than to the

females except carbaryl, which was more toxic to females.

Rudinsky and Terriere (1959) also conducted residual tests using the same LD_{50} and LD_{90} analysis in comparison with spray contact tests. D. pseudotsugae was shown to be more susceptible to insecticides in contact with the tarsi than with the body surface during the spray tests. Endrin, Thiodan, isodrin, and lindane were most toxic and chlordane was the least toxic. Carbaryl, DDT, dieldrin, aldrin, and heptachlor were intermediate in toxicity. Over a 13 week period under field conditions, endrin, Thiodan, and isodrin gradually declined in residual effectiveness. Lindane, aldrin, heptachlor and chlordane showed the most rapid decrease. DDT demonstrated the least decline in residual toxicity and showed about one-third its original toxicity after 13 weeks. Lindane, aldrin, heptachlor, and chlordane became ineffective in six weeks, and dieldrin and carbaryl in about 10 to 12 weeks. Endrin, Thiodan, and isodrin each lost most of their toxicity in 13 weeks.

Mechanical control. The mechanical control of forest insects is also known as sanitation and salvage control. The mechanical control procedures are aimed at destroying bark beetles in infested trees. Hopkins (1909a) discussed the general methods for control of 23 species of Dendroctonus in North America. He stated that a good knowledge of the species habits and seasonal life history are essential for successful and economic control methods.

Since removal of the bark of standing trees can kill the broods, especially larvae, then suitable tools such as spuds, used by pulp cutters in removing bark, were recommended for any bark removal operation. Destruction of the broods without removal of the bark can be accomplished by harvesting the infested trees for (a) immediate processing into lumber and burning the slabs; (b) submerging the logs in the water in order to preserve the wood and kill the beetles; (c) piling the logs and burning them along with the bark; (d) opening the bark on the upper surface to allow penetration of rain water; or (e) moving of the logs 20 to 50 miles away from any forested area. By this method of control, the beetle population is reduced by 50 to 75% which will prevent aggressive attacks upon healthy trees. A prerequisite for this kind of control would be prompt recognition of an epizootic in its early stages when only a few trees have become infested. Successful control of extensive invasions must be carried out in the winter months before the broods begin to emerge in the spring. The object of the control should be removal of a large percentage of infested bark in order to destroy the greatest possible number of broods.

Removal and burning of infested bark is effective in controlling epizootics in the southern United States. The logs may be burned to destroy broods without removing the bark first. Summer control may be desirable in a clear cutting operation. Piling tops, limbs, and bark on stumps

and logs for burning is advisable for good control (Hopkins, 1909a; Evenden et al., 1943; Kowal, 1960; Thatcher, 1960; Dixon and Osgood, 1961).

Hopkins (1921) published a summary of control recommendations against D. frontalis in the southeastern United States. These recommendations were aimed at destruction of the over-wintering broods in the bark between November and March. The epizootics were to be treated as promptly as possible. He also listed other details as follows: (a) it is unnecessary to burn tops or branches; (b) it is only necessary to remove the bark where the beetle broods are located in the trunk; (c) no summer harvesting of timber should be carried out if beetles are in the region because adult beetles are attracted within a radius of three or four miles of sites of harvest operations in the summer; and (d) forest owners should not undertake control work until they are familiar with the essential details in control methods. The success of a mechanical control operations of any method depends upon their adaptation to local conditions, which includes disposing of infested timber and destruction of the broods.

Solar radiation upon felled trees has produced high mortalities to the bark beetle broods. Turning the logs completely one to three times was required to kill the insects, depending on the thickness of the bark (Evenden et al., 1943; Massey and Wygant, 1954; Dixon and Osgood,

1961).

The use of trap trees and logs has produced varied results. Immediate harvest or destruction of infested trap trees or logs is necessary as a control measure (Massey and Wygant, 1954; Thatcher, 1960).

Perry (1951) discussed some mechanical control procedures for Mexico, such as felling, peeling, and burning in local areas which is successful when the work is done thoroughly. No new attacks had occurred around the treated areas one year after this control measure, which paid for itself from sale of the wood. Perry also discussed regulated cutting, proper management of pine stands, and replanting with more resistant pine species as a feasible method for prevention of epizootics.

Between 1962 and 1966, an extensive D. frontalis epizootic in Honduras, Central America denuded over 5,000,000 acres of valuable timber land. Since the beetle can produce nine to 15 generations a year in this year-round warm climate, mechanical and chemical control methods were ineffective (Ketcham and Bennett, 1964;[11]).

Biological control. The insect parasites known to attack D. frontalis belong to six families of Hymenoptera and four families of Diptera. The majority of the known parasites are Hymenoptera:Braconidae (Table 8). The parasites oviposit through the bark into the galleries while smaller parasites enter the host galleries and lay

their eggs in the host egg niches or in the larval galleries. Some oviposit on or in the host. The parasitic larvae seek out the host after hatching if they are not oviposited directly on the host (Thatcher, 1960).

Hetrick (1940) reared parasites from logs infested with D. frontalis and listed them in the order of abundance as follows: Coeloides pissodis, Cecidostiba dendroctoni, Spathius canadensis, Heydenia unica, Roptrocerus eccoptogasteri, and Dendrosoter sulcatus.

Rudinsky (1961) suggested that the insect parasites were probably more effective in keeping the bark beetles in control when other conditions were not favorable for epizootics. Knowledge of the abundance of natural enemies and their life habits is essential in order to adopt precautions for their protection. Such practices as leaving the thinner bark and crown portions of the trees for parasite emergence will increase their potential for control purposes (Hopkins, 1909a).

Cleridae and Tenebrionidae (Table 9) are common predators of D. frontalis (Dixon and Osgood, 1961). However, they are not considered decisive factors in epizootic collapses (Rudinsky,1962).

Hopkins (1893) found that the clerid, Thanasimus dubius, was predaceous on D. frontalis. He also imported large numbers of Thanasimus formicarus from Europe as the first intentionally introduced biological agent to control

forest insect pests in this country. The epizootic of D. frontalis under study declined before evaluation of the introduced predator was determined (Hopkins,1893). The predator was probably not successfully established.

The predatory clerid larvae feed on the larvae and pupae of D. frontalis. The adult predators feed on the adult bark beetles on the bark surface. Fronk (1947) found the common predators were Tenebroides collaris, Temnochila virescens, and Thanasimus dubius. One larva of Thanasimus dubius was observed to feed on 96 larvae of D. frontalis during its development in the bark (Fronk,1947). Bennett[9] stated that a predatory clerid larva in its life span can destroy 300-400 immature D. frontalis, in four to six weeks. The adult beetles can destroy 100-200 adult D. frontalis. During its life span, one clerid predator per 20 D. frontalis was said to reduce the host bark beetle population by 33%. A generation of a clerid brood lasts 70-100 days, depending upon the season of the year. The adults live for approximately two months and deposit about 350 eggs each.

Table 10 presents the arthopods, other than insects, associated with D. frontalis in Mexico and Honduras. The potential of the mites as biological control agents in Mexico is unknown. Moser[12] reported that mites, Uropoda sp. and Pygmephorus sp., were important biological agents against D. frontalis in the United States. The Uropoda sp.

cover the adult beetles for phoresitic reasons and may mechanically prevent locomotion, flight, and copulation when abundant. Fronk (1947) found numerous Uropoda sp. in phoresy on D. frontalis. As many as 40 mites were counted on one beetle. The mites attach by means of a pedicel of excrement. About 80% of laboratory reared beetles had mites or the pedicel attachment. The Pygmephorus sp. preyed on the young bark beetle larvae. He reported also that mites of Tarsonemoides sp. were predaceous on eggs.

Thatcher (1960) listed the mites in the United States that were predaceous on larval D. frontalis as Parasitidae; Parasitus sp. and Histogaster carpio (K.). Other mites, of which we have little knowledge concerning their type of association, were Uropodidae: Uropoda sp.; Dameosimidae sp.; Cheltidae: Cheltia sp.; Laelaptidae: Dendrolaelaps sp., and Zercoseius sp.; and Oribatoidae sp. (Thatcher,1960).

Parasitic nematodes that attacked larvae of D. frontalis were Aphelenchulus barberus Massey and Angullonema sp. The nematodes were transported beneath the elytra of adult beetles from tree to tree (Hetrick,1940).

Woodpeckers commonly strip the bark from dead trees in search of all stages of bark beetles (Thatcher,1960). Smith and Lee (1957) stated that the most effective woodpecker control occurs in thin barked trees or in the crown section of larger trees. The woodpeckers probably have little effect in reducing bark beetle epizootics (Dixon and

Osgood,1961).

The role which pathogens have in regulating the population of bark beetles is unknown. No bacteria or viruses have been reported. Two fungi in the United States, Cylindricola dendroctoni Peck. and Beauveria sp. (Dixon and Osgood,1961), and Cryptoporus volatus in Mexico (Moreno, 1954) attack D. frontalis.

Kowal (1960) reports that the full effect of parasites, predators, diseases, and woodpeckers have not been determined for D. frontalis. He felt that even though they exerted some control, they rarely had a notable control effect during severe epizootics.

Clark[8] discussed epizootic declines due primarily to interspecific and intraspecific competition of bark beetles, insect parasites, predators, and mites. Denton (Rudinsky, 1962) reported a D. piceaperda epizootic decline because of simultaneous invasion by Ips. perturbatus. Ips sp. infested and developed in the cambium region faster than Dendroctonus sp. and deprived the latter of food. Bennett[9] reported that U. S. Forest Service entomologists, who observed the D. frontalis epizootic in Honduras, stated that a general collapse of the epizootic and a noticeable increase in natural enemies occurred three years after the beginning of the epizootic.

Materials and Methods

Laboratory Experiments

Spray applications. The spray application experiments in the laboratory were conducted at Chapingo, Mexico, with logs infested with D. frontalis (Figs. 39-42). All logs were cut from heavily infested Pinus leiophylla on the Ex-Hacienda Manzanilla, Puebla, Puebla, Mexico and were transported to the laboratory at Chapingo.

Seventy heavily infested logs were used, 48 for chemical treatment, 12 for check purposes, and 10 for sampling. Systematic sampling of test logs yielded an estimate of all stages of the population during the tests. A random selection of the logs was made for sampling purposes. Several belts of bark, 10 cm wide, were taken from each sample log. Ips sp. were also counted when abundant (App. 15).

The insecticides selected for the laboratory and field experiments were benzene hexachloride (BHC), and malathion, ethylene dibromide (EDB), and carbaryl. Appendix 16 shows the laboratory trials periods, dates of insecticide manufacture, and the per cent of active ingredients. In the case of BHC the active ingredients represent the percentage of gamma isomer. The standard formula used for calculating the desired concentration of the insecticide and the quantity of liquid carrier on a weight basis was $X = \frac{a\ b}{c}$, where "X" equals the quantity of the commercial formulation

to be used, "a" the quantity of the carrier necessary to cover three 85 cm logs, "b" the per cent insecticide necessary, and "c" the per cent of active insecticide in the commercial product. All measurements were made by using the metric system.

Concentrations were increased or decreased by arithmetic progression in laboratory trials following analysis of previous trials. If results showed little control, the insecticide was increased by one higher concentration, whereas, if results showed effective control, the ranges were decreased to the next lower concentration.

The insecticides were applied as suspensions of emulsions in water in the first laboratory trial. The preliminary results with water were not effective since the insecticide did not penetrate the bark. Various oil solvents were then tested for penetration of the tree bark. Diesel oil with a penetration time of 20 minutes for a one-half inch thickness of bark was not the most rapid in penetration ability, but it was selected since it was relatively inexpensive and readily available. After preliminary tests, a 25% diesel oil emulsion was selected for use in the laboratory and field trials.

Liquid insecticides (malathion and EDB) were measured in calibriated glass graduates while the powders (carbaryl and BHC)were weighed on a torsion balance. The concentrations were mixed in sequence from the lowest to the

highest to reduce the chances of contamination error. After measurement, the materials were mixed in six-liter pails and agitated to gain the necessary suspension or emulsion (Fig. 39).

During application, the mixtures were continuously agitated and the spray gun nozzle was held close to the log to reduce spray loss. The most suitable application time was in the morning before 9 AM, when the air was still. The mixtures were sprayed in order from the lowest to the highest concentration to reduce the chance of contamination error in the spray equipment. Spray was continued until "run-off" began. A separate spray pump-gun was used for each insecticide (Figs. 39,40,44).

The quantity of liquid carrier needed to spray a log (85 X 15-30 cm) to the "run-off" point was calculated from preliminary trials to be between 1200 and 1500 cc. A volume of 1500 cc was adopted to compensate for the variations in log diameter.

Safety precautions were taken to avoid injury to personnel who handled the insecticides. The operators wore rubber gloves while mixing the chemicals and two-filter, nose and mouth respirators during spray applications. All chemicals were mixed with care and the equipment was thoroughly washed with water after use (Figs. 39,40,44).

The equipment consisted of four 6-liter pails for mixing the insecticides and an extra pail of clear water

was used for cleaning the spray guns. All pails were labelled and were always placed in the same order during mixing, spraying, and washing to avoid errors. The pails used for mixing insecticides were thoroughly washed when insecticides or spray concentrations were changed. Each spray pump was flushed with water by ten or more double action strokes between different mixtures to minimize contamination (Fig. 39).

Each treatment was applied to three Pinus leiophylla logs between 15 and 30 cm in diameter taken from heavily infested areas and sawn with a chain saw in the field into the 85 cm lengths to fit into the barrels (Figs. 31,40). These logs were cut from the bole below the crown to reduce the chance of interference by Ips sp. Upon arrival at the laboratory a coating of paraffin was painted on the cut ends of the logs to reduce moisture loss. Sixty 85 cm logs were cut for each laboratory trial; twenty barrels were available, allowing three logs for each barrel. The logs were sprayed in the open and allowed to dry indoors before being placed in the 200 liter steel barrels in the laboratory. Three untreated logs were used as checks for each treatment. Each insecticide was applied at four concentrations (one concentration per barrel), and four barrels with untreated logs were used as checks. The same type of insecticide was always used in the same barrel and the check logs were always in their own barrels.

The barrels rested on their side in two wooden racks. Four glass jars for collection of emerged insects were placed on the barrels by soldering the jar covers to the barrels (Figs. 31,41,42). The bottom jar allowed easiest access for the insects to travel into the collection jar. Eight white fluorescent lamps supplied continuous light in the room to attract the insects into the jars. One end of each barrel was replaced with a plastic screen covered by a black tailor cloth and held in place by nylon cord to prevent escape and reduce light, but to allow ventilation (Fig. 31,41,42).

Insect mortality in the laboratory logs was compared with untreated check logs. Preliminary tests indicated that, if the insecticides had lethal effects, the action was completed within 24 hours. The emerged insects in the collecting jars were counted daily and placed in petri dishes, which were then placed in an incubator at 23 C for 24 hours. Mortality of the insects was checked after 24 hours by stimulating the insects with a dissecting needle and noting any movements of the antennae and legs. Beetles were considered dead if no movements occurred after stimulation. All beetles that died inside the barrels were collected at the end of the experimental trial, counted, and added to the tabulation. After beetle emergence terminated, no stages of the beetles remained in the logs.

Since the laboratory consisted of an inside room

the temperature conditions inside the barrels remained almost constant. Near the end of Trial 1, a hygrothermograph was placed in a barrel to record the temperature and relative humidity for all subsequent trials.

Water emulsions and suspensions were used in the first trial. After preliminary tests, Atlox 3387, was selected to emulsify EDB in water which was heated to 25-30 C before mixing.

In Laboratory Trials 2-6, 25% diesel oil in water with 50 cc of Triton X-100 emulsifier was used to produce an oil-water emulsion which would assist the insecticides in penetrating the tree bark to kill the insects before emergence. Preliminary tests showed Triton X-100 to be a superior emulsifier for diesel oil and water with the insecticides used. Twenty emulsions of the four insecticides were tested in a preliminary experiment to establish this fact.

The insecticides were stored at 15-20 C in rooms without windows. The dates of the trials and the insecticidal formulations are shown in Appendix 17. The spray concentrations used for each insecticidal treatment are given in Appendix 18-21.

The four spray guns, one for each insecticide, used in Trials 2-6 were "trombone" double action, hand operated spray guns (H. D. Hudson Co., Chicago, Illinois). Specifications of the spray guns were: cylinder 3/4" X 16 1/2,"

plunger and air chamber 1/2" X 21," hand grip gun type, pressure 180 lbs., pump capacity of 1.3 oz per stroke, and weight 2.5 lb. The body of the spray nozzle rotated and was adjustable to allow a wide, fine cone spray or a narrow solid stream of liquid. The cone spray was applied to the logs with the nozzle close to the target during application to reduce spray loss due to drift.

Clean sawdust and shavings were used in the collecting jars, which were removed daily with the insects. Fresh sawdust and shavings were put into the collecting jars each day to give the beetles a footing to prevent them from injuring each other by chewing off each others legs when struggling to regain a standing position. Fresh sawdust daily also reduced the possible insecticide contamination of the jars. The petri dishes, in which the beetles were observed after being removed from the collecting jars, were cleaned with actone solvent after each 24 hour observation period. The same petri dishes were used each day for the same insecticide concentration.

A ventilation system was used to reduce the relative humidity in the barrels during Trials 2-6. Air was forced through each barrel to produce better ventilation and to reduce possible fumigant action from the insecticides (Figs. 31,41,42). A one h.p. electrical motor driving a fan supplied air to the 10 barrels through three inch galvanized pipes with rubber connections to the barrels. The

air going into each barrel was controlled by valves (Figs. 31,41,42).

It was anticipated that the changes of air would help to simulate open forest conditions. The fans were operated about two hours daily, usually between 12 AM and 2 PM, to prevent desiccation of the logs and to allow for a complete change of air. Air temperature in the laboratory room was maintained at 19 to 22 C.

In Trial 6, Aphis sp. on the stems of the legume plants, Acacia sp., were placed in each barrel including a check barrel to determine possible fumigant action from the insecticides. The Acacia stems in a vial of water that was glued inside a small cardboard box (Fig. 48), were infested with more than 50 aphids per stem. At the end of 48 hours the aphids were observed for mortality and dislodgement from the plant.

Topical applications. A preliminary bio-assay test was carried out on D. frontalis by a dipping technique. The insecticides used were BHC, dieldrin, carbaryl, malathion, and methoxychlor. Three hundred larvae and adults were used in insecticide concentrations of 0.0012, 0.0037, 0.011, 0.033, and 0.1% of the active ingredients. The insects in a cloth strainer were dipped for three seconds into various insecticide concentrations and were then placed on filter paper in petri dishes to dry. Mortality checks were taken 24 and 48 hours after treatment. These results were not

suitable for analysis because the dosage per insect was unknown, therefore the tests were discontinued.

Further topical tests were conducted using a topical micro-applicator (Fig. 47). This apparatus, built by the Insecticide Department, Rothamsted Experiment Station, England used 12/24 volt D.C. current or could be operated manually. It contained an automatic plunger for the 3/10 mm syringe which discharged measured amounts from 0.1 to 1.5 microliters.

Seven tests, three on larvae and four on adults, were conducted. Each test was run with BHC wettable powder and malathion emulsifiable concentrate at concentrations of 0.0012, 0.0037, 0.011, 0.033, and 0.1% of the active ingredient. The commercial formulations of the insecticides tested were those used in Laboratory Trials 5 and 6 described earlier.

The various concentrations were prepared by first mixing a 0.1% concentration and then placing 5 ml of that concentration into 10 ml of distilled water to form the next lower concentration. This operation was repeated until a 0.0012% concentration was mixed. Application of the insecticide began with the lowest concentration and continued to the highest in order to reduce contamination. The syringes and needles were cleaned with acetone solvent between all treatments.

Three replicates, each using 10 insects, were run

with each concentration. Ten insects were placed in a petri dish on filter paper and each insect dosed topically, wetting the insect thoroughly by manual operation with 1.5 microliters of the insecticidal concentration. The insects were held at about 20 C during the observation period. Observations after stimulation with a needle of the antennae, legs, and other body movements, were taken at 24 and 48 hours to determine mortality.

Field experiments. A field test was attempted in July 1963, but heavy rain interfered with the work, hindered access to the infested area, and washed off much of the insecticidal residue from the tree trunks, and the experiment was discontinued. These tests described here were applied between January and May in 1964 to avoid the rainy season in Central Mexico. The field trials were located on the Ex-Hacienda Manzanilla, Puebla, Pueble, Mexico (Figs. 43-46).

The insecticides were applied at the following concentrations: malathion and BHC gamma isomer 0.50, 1.00, 1.50, and 2.50%; EDB and carbaryl 1.00, 1.50, 2.50, and 4.00%. Each concentration of insecticide was applied in three concentrations of diesel oil-water emulsions at 25, 37.5, and 50%, and each mixture was replicated twice. The insecticidal concentrations for these tests were determined after analyzing the results of Laboratory Trials 2 and 3. Ninety-six trees were treated with insecticides and 48

untreated trees were used as checks.

The test sample was a section of tree trunk 50 cm from the ground and 255 cm long, sprayed to "run-off" with the insecticide. The 255 cm length of tree trunk was equivalent to the three 85 cm logs used in laboratory tests.

The test tree sections were marked with yellow painted bands and code letters, numbers, and warning signs. Warning signs were necessary because the country people take the dry bark of dead trees for fuel after they have been killed by the bark beetles.

The insecticide mixtures were prepared and applied in the field near the infested trees, using the same methods as those described in Laboratory Trials 2 and 3.

All trees within the test area were heavily infested but still had green crowns. Preliminary sampling showed the developing brood was in the egg or early larval stage, two or three weeks after the initial attack. Each of the four insecticides was sprayed on separate groups of Pinus leiophylla trees in the plantation.

Although the study was intended only for D. frontalis, Ips sp. were observed also. The Ips sp. attacked only the crown in the beginning stages of the epizootic but as they increased in number they spread over the entire tree trunk.

Final population counts were made after felling the trees and examining the bark (Fig. 45). Five belts of

bark, 10 cm wide, were marked off around the tree trunk at 100, 150, 200, 250, and 300 cm from the ground, and all exit holes within these zones were counted and tabulated. The freshly cut reddish brown exit holes were easily distinguished from the old gray gallery ventilation holes. Treated trees were compared with check trees to assess the toxicity of the treatments.

Results

Laboratory Experiments

Spray applications. A definite effort was made during the trials to cut logs with a high population of D. frontalis. The populations of D. frontalis and Ips sp. were estimated at the time of the insecticidal applications (App. 15). In Trials 1 and 2 the Ips population on the main trunks was very low. In Trials 3, 4, and 5, it was impossible to find any trunks without a high population of Ips sp. However, trunks were selected that contained only D. frontalis and in Trial 6. The Ips sp. were identified as Ips bonanseai and Ips cribricollis. The reduction of D. frontalis, during Trials 5 and 6, was associated with Ips sp. which had migrated from their normal bark niches in the crown portion of the tree to cover the bark of the entire tree trunk, causing intensive interspecific competition for food and space. Intraspecific competition, parasites, and predators all aided in reducing the population of

D. frontalis. A more complete discussion of the collapse of the epizootic can be found in Section III under "Biological control notes."

During Trials 2-6 a hygrothermograph was placed in a barrel containing sprayed logs. The temperature ranged from 18-27 C over the two year duration of the trials. The relative humidity ranged from 50 to 97% for Trials 1 and 2. The high humidity was produced by evaporation of water from the logs in the barrel. After installation of the ventilation system, the relative humidity was recorded between 40 and 72%.

The insecticide treatments using water alone as the diluent in Trial 1 were less effective than those in which an emulsion of diesel oil and water was the diluent in Trials 2-6 (App. 18-21). However, BHC was much more effective diluted in water than were the other insecticides in Trial 1 (Fig. 30).

The insecticidal applications in Trials 2-6 were emulsions of diesel oil and water. The diesel oil was added to aid penetration of the insecticide into the bark. Four spray tests, employing 25% diesel oil-water emulsions (without insecticide), were applied to logs in four barrels in Trial 2. These four tests averaged 2,324 emerged insects compared to 2,267 insects from the untreated check barrels, indicating no toxicity from the diesel oil emulsion alone without insecticide.

Most of the emerged insects were collected in the bottom collection jars but many dead beetles were found inside the barrels after the trial was terminated and were counted as emerged beetles. This suggested possible fumigant action and was one of the reasons why the ventilation system was installed in the beetles. In Trial 6 aphids were placed in each barrel with the treated logs and also in a check barrel with untreated logs (Fig. 48). Observation after 24 hours showed no significant difference in aphid mortalities, but differences were significant after 48 hours. Aphid tests were run at 4, 14, and 39 days after treatment of the logs. No actual count of the aphids was made but all the sprays as well as the check showed some aphids had died, moved, or had fallen from the plants. The mortality in the sprayed barrels, when compared with the checks, showed no noticeable mortality or "knock-down" for EDB or carbaryl. The malathion, at 0.75% concentration in the three tests, showed a significant aphid mortality. The BHC, at gamma isomer concentrations of 0.012, 0.025, 0.05, and 0.10%, showed a significant aphid mortality and all aphids, including those surviving, were no longer on the plants. Therefore, the fumigant action tests suggest that an unknown percentage of the mortality from BHC and perhaps also malathion resulted from the fumigant action of the insecticide in the barrels. All concentrations of BHC in Trials 2-6 produced above 90% mortality on D. frontalis

except the lowest (0.012% gamma isomer) which produced a 79.3% mortality (Table 13).

The detailed results from Laboratory Trials 2-6 with the four insecticides against D. frontalis are summarized in Table 13.

Eleven analyses of variance tests on the percentages of mortality were run on an IBM 1620 computer at Chapingo, Mexico. Data were analyzed with and without transformation. The transformation was arc sin square root of the per cent which was used to form a more normal curve for distribution of the data. Neither the original nor the transformed data showed any significant differences in Trials 2-6. Trial 1 did show a higher significant percentage of mortality for BHC in both analyses when compared with the other insecticides used in this test.

A Chi Square test for "goodness of fit" was run on the data to see if it was possible to average the percentages of mortality of all the insecticides combined. These tests were negative since the data did not fit a normal population curve.

Another test was run on the data in Trials 2-6 as a simple analysis of covariance. This test showed no significant difference between the insecticides when all the concentrations were averaged.

The best analysis of the data to demonstrate the differences between insecticides and concentrations of each

was the probit analysis. The percentages of mortality were plotted on logarithmic probability paper (Figs. 26,27). The computations of fitting for a probit regression equation for each insecticide are given in Tables 14-17. From the logarithmic probability paper and the computation fitting, the LD_{50}, LD_{90}, and LD_{95} for each insecticide were determined.

The LD_{50} per cent concentrations for BHC, malathion, EDB, and carbaryl, from the logarithmic probability paper, were, respectively, as follows: 0.00265 (per cent gamma isomer), 0.032, 1.120, and 0.850% (Figs. 26,27).

The LD_{90} per cent concentrations for BHC, malathion, EDB, and carbaryl, from the logarithmic probability paper, were, respectively, as follows: 0.0225 (per cent gamma isomer), 0.210, 2.125, and 1.920% (Figs. 26,27).

The LD_{50} per cent concentrations for EDB (Table 16) and carbaryl (Table 17), from the computation fitting within the fiducial limits, ranged from 1.059-1.059 and 0.5750-0.5758% respectively.

The LD_{95} per cent concentrations for BHC, malathion, EDB, and carbaryl, from the computation fitting within the fiducial limits, ranged from 0.07140-0.07183 (per cent gamma isomer), 0.3503-0.3511, 2.106-2.107, and 2.624-2.643% respectively (Tables 14-17).

BHC was the most toxic insecticide to D. frontalis. Malathion was only slightly less toxic when compared to

BHC, since only 0.279% difference occurred between the two insecticides at the computed fitting for LD_{95}.

EDB and carbaryl were much lower in toxicity to D. frontalis than BHC and malathion. The regression lines for these two insecticides were very close together and almost parallel (Fig. 27). The difference between EDB and carbaryl at the computed fitting for LD_{95} was 0.518-0.536 (Tables 16, 17). EDB was least toxic to D. frontalis when compared with the other insecticides.

Since Ips sp. were numerous in Trials 3-5, the effectiveness of the spray applications against these insects was checked also. Ips bonanseai and Ips cribricollis were more susceptible to all concentrations of all insecticides than was D. frontalis (Tables 18, App. 22-25). All mortalities for the Ips sp. were abcve 96% except one average mortality of 87% for malathion at the lowest (0.125%) concentration tried (Table 18).

At all times some Ips sp. occurred in the epizootic area in the crown, trunk, and limbs. During Trials 1 and 6 no Ips were collected from the barrels with logs cut from the main trunk of the tree for the D. frontalis experiments. A total of only 86 Ips sp. were collected from all barrels in Trial 2.

A total of 62 bark beetle parasites was collected from all barrels in Laboratory Trial 1. Less than 50 parasites were collected in Trial 2. The population of parasites

obtained from the check barrels fluctuated greatly during Trials 3-6 (App. 16). The parasites emerged during a period of almost three months, from the time of spray application to termination of the trial. The decline of parasites in the check logs in Trial 5 occurred at the same time as the decline of Ips sp. The large increase of parasites in the check logs in Trial 6 (App. 16) may have been caused by the parasites concentrating attacks on the few D. frontalis that were in only about 10 trees left at the end of the epizootic.

The results of the insecticidal treatments in Laboratory Trials 3-6 on the parasites of D. frontalis and Ips sp. are shown in Table 19 and Appendix 26-29. All insecticides at all concentrations in these tests were highly toxic to the parasites. No mortalities were below 94% (Table 19).

No clerid predators were observed in Trial 1 and only a few in Trial 2. Little increase in abundance of clerid predators occurred during Trials 3-6 (App. 30-33). The results of the insecticidal treatments, on the clerid predators of D. frontalis and Ips sp. are shown in Table 20. All insecticides at all concentrations produced mortalities above 82% (Table 20).

Topical applications. Seven topical application experiments with BHC and malathion on adults and larvae of D. frontalis were completed over a three month period. The results, as observed after 48 hours, are shown in Table 21;

Appendix 34; and Figure 28.

Significant differences of treatments and their interactions were demonstrated by analysis of variance (App. 34). All data were transformed to arc sin square root of the per cent to normalize the data distribution.

No significant difference in toxicity was found between BHC and malathion in any of the experiments. Both insecticides, however, were more toxic to adults than to larvae (App. 34). Malathion was only slightly more toxic than BHC to the adults, while BHC was somewhat more toxic to the larvae.

The difference between the 24 and 48 hour observation time for mortality was found to be highly significant at both the 5 and 10% levels. The 48 hour recording time was used since it proved to be more accurate (App. 34).

A highly significant difference at both 5 and 10% levels was found between the various insecticide concentrations of BHC and Malathion. As expected, they both had a linear scope away from zero. The LD_{50} and LD_{90} for the larvae tested with BHC and extrapulated from logarithmic probability paper were respectively 0.068 and 1.55 per cent gamma isomer, and for Malathion they were 0.084 and 2.00%. The LD_{50} and LD_{90} for adults tested with BHC were 0.0076 and 0.31 per cent gamma isomer, and with Malathion they were 0.0074 and 0.13% respectively (Fig. 28).

Field Experiments

Spray applications. January to May are usually dry months in Central Mexico (App. 14). No rain fell during these months of the field trials. Temperature recordings were made for three days in January and two days in May (Figs. 4,5,11,12,13; App. 8-12). Daily temperatures fluctuated between 4.4 and 26.7 C for air temperature measured one meter above the ground during the dates of application and tabulation of results. Before the field application of insecticides began in January, a random sample of trees to be sprayed was observed to determine the bark beetle species present and their density. A high population of beetles was indicated by a large number of entrance holes or pitch-tubes on the bark surface of the sample trees. The sample showed a majority of D. frontalis beetles with some Ips beetles, both varying in density between trees and groups of trees. Species identification was determined by the character of the galleries observed after bark removal. The results were analized for D. frontalis, but Ips bonanseai and Ips cribricollis could also be included in the interpretation of results since they were also located in the same trees. All beetles were found in the larval stage and all trees had green foliage at the time of spray application.

Each insecticide was applied to a distinct group of trees separated from the other tests by 300-1000 meters. About four months after spray treatment, the number of exit

holes in the bark of both untreated and treated trees were counted. Insect populations of treated trees, as determined by the numbers of exit holes, were compared with the populations of unsprayed check trees in the same group. The EDB test was conducted in a stand of small trees with diameters about 12 years old from 10-20 cm DBH. The other insecticides were sprayed on trees 26 years of age and about 30-40 cm DBH. The average beetle population per check tree for the spray plots were 1,287 for BHC, 779 for malathion, 374 for EDB, and 1,023 for carbaryl. The beetle population varied greatly between different trees and within the same group and between different groups (App. 35).

Populations were determined by the number of exit holes counted in belts of bark 10 cm wide around the trunk of the trees (Fig. 45, App. 35). The mortalities for the treated trees are given in Table 22. Despite precautions, some bark from treated trees was removed by natives for fuel. This accounts for the missing data in Table 22 and Appendix 35. Twelve trees were so damaged by natives gathering fuel that only partial samples could be taken from them. Thirteen trees treated with EDB and five trees treated with carbaryl were completely removed by the natives.

The various emulsions used to dilute the insecticides made no difference in the control obtained. Oil and water emulsions with 2.5, 37.5, and 50% diesel oil all

gave similar results. These observations showed that probably 25% diesel oil in water was sufficient for adequate penetration of the insecticides and high mortality of the beetles (Table 22, App. 35).

The results of the treatments showed that BHC was the most effective insecticide, as it gave good control at all concentrations and replications. Concentrations of 1.50 and 2.50% gamma isomer produced the highest mortalities (99.3-100%), but concentrations of 0.50 and 1.00% gamma isomer were only slightly less effective (88.1-100%); (Table 22, Fig. 29).

The treatment with malathion gave control almost as effective as BHC at all comparable concentrations and in all replications. Again 1.50 and 2.50% active insecticide produced the best control (84.3-100%); (Table 22, Fig. 29).

The results of EDB treatments were not suitable for analysis since much of the data were missing due to removal of trees or bark for fuel. However, the data obtained showed very little increase in control when concentrations were increased from 1.00 (the lowest concentration tried) to 4.00% the highest (Table 22, Fig. 29).

Increasing the concentration of carbaryl insecticide from 1.00 (the lowest concentration tried) to 4.00% yielded increased control, but at 4.00% control was still inadequate (Table 22, Fig. 29).

The mortality data are shown on logarithmic

probability paper as probits (Fig. 29). The LD_{90} for each insecticide was as follows: BHC 0.042% gamma isomer, malathion 0.45%, EDB 2.60%, and carbaryl 2.38% active ingredients (Fig. 29). The field results were very similar to the laboratory results (Figs. 26,27), with BHC, the most effective insecticide used, and malathion next in effectiveness. Field results with EDB and carbaryl correlated closely with the laboratory tests. Carbaryl proved slightly more toxic than EDB and both were well separated from BHC (Fig. 29).

BHC produced high mortalities at all the concentrations tried. Its toxicity, persistence, and probable fumigant action gave it important advantages over the other materials used. BHC is the cheapest of the insecticides; it is formulated in Mexico and readily available there. Malathion also gave effective field control, but it is costlier and slightly less effective than BHC. In Central Mexico, EDB and carbaryl probably should not be recommended for control of an epizootic because they were ineffective in these tests.

Mechanical control and salvage operations. Field observations were made of two mechanical control attempts on different terrain. Different terrain conditions required different materials and methods (Tables 11, 12; Figs. 32-38).

The mechanical control was very similar to a

harvest operation, the only major difference was burning of the peeled bark to destroy the beetles. These operations were necessitated by the beetle epizootic and were conducted primarily to control the beetle while salvaging the dead timber was a secondary consideration. The expenditures and receipts per cubic meter of harvested wood for both terrain locations are shown in Tables 11 and 12.

One study area is mountainous terrain in an uneven-aged pine forest. This forest land was an "Ejido," or cooperative farm. This epizootic was located near the town of Nicolas Romero about 70 miles northwest of Mexico City. The wood was purchased from the owners by an experienced woods operator. The Federal Forest Service marked all trees attacked by the beetles that were to be cut and aided the woods operator in organizing the operation. Trees were cut by hand tools such as axes, cross-cut saws, and wedges. Transportation was by burros to a main haul road where it was moved by trucks to Mexico City.

The trees were felled, the bark was peeled, and the logs were bucked into 50 cm lengths and split at the site. The bark top and branches were piled and burned over the stump or on the side of it. The bolts were then bucked into 50 cm sections and split for pulp use. The branches larger than 5 cm in diameter were cut into 50 cm lengths for firewood. The pulp and firewood were then transported on burros to a truck loading area near the

highway. The wood was shipped by trucks to Mexico City to the paper mill and the various firewood yards (Figs. 32-38).

The second area of investigation was located 90 miles east of Mexico City and two miles from the city of Puebla in a pine plantation on the privately owned Ex-Hacienda Manzanilla. Both even and uneven-age stands of pine were located on the Ex-Hacienda, and the epizootic had started in an uneven-age stand. The observations were made for the most part in an even-age planted area of pine trees, 26 years of age.

Trees were cut by axes, cross-cut saws, chain saws, and wedges. Flame-throwers were used to help start fires. Transportation was by tractors, wagons, and trucks. All vehicles could easily move about the harvesting area since the land was level and the bottom was hard.

The operation was carried out by the land owner after the beetle infested trees in the plantation area were marked by Federal Foresters. The trees were felled, debarked, and bucked into 50 cm lengths with both hand and power tools, then split for pulpwood use. The stumps were peeled to the ground line as a control measure. Branches larger than 5 cm in diameter were cut into 50 cm lengths for firewood. The bark was piled and burned and fires were started with a flame-thrower or torch. Some trees were skidded, full size, after felling and peeling, to a landing and were later bucked into pulpwood lengths to

speed up the control operation.

Branches over 5 cm were cut into 50 cm lengths and stored for later trucking to the city. Some of the bark and small branches under 5 cm were carried off by natives for firewood. The demand for firewood was evidenced by the stumps that were dug out of the ground by the natives for fuel or were sold in the city for firewood. As the bark dried and loosened on severely attacked standing trees, the natives peeled the bark to about 5 meters in height for firewood. The insects were in the late larval instars or pupal stage when this occurred. This probably caused little beetle mortality since the beetles in these stages can survive and develop in the dry bark from this informal bark harvest. These operations can be seen in Figures 32-38.

Operating on the plantation cost about seven pesos (0.56 dollars) less per cubic meter than in the mountainous region. The main cost difference in the mountain region was payments of 15 pesos (3.20 dollars) per cubic meter to the woods operator for the wood. The burro operations in the mountainous region were cheaper than tractor skidding on the plateau, but the tractors were superior because of their speed. To keep the plantation machinery active, a larger labor force was necessary and the expenditures for harvesting occurred over a shorter length of time. Time is the most important factor in mechanical control of a bark beetle epizootic.

The control that resulted from both harvesting operations was not successful. D. frontalis beetles were observed in the forested areas treated. The final collapse of the epizootic in both areas was probably caused by natural factors working against the spread of the epizootic rather than the control measures.

The reasons for lack of success in mechanical control of the beetles were: (1) the Federal Foresters did not mark new trees as they became infested during the harvesting operations, bringing both the operations to a temporary halt; (2) dead trees from which the beetles already had emerged were felled first, missing the opportunity to kill beetles still present in more newly infested trees; (3) manpower was insufficient to harvest infested trees within the 30 to 60 day period necessary to kill the beetles before they emerged; and (4) modern equipment such as chain saws which could have greatly reduced harvesting time were lacking.

Biological control notes. Only limited data on the parasite, predators, and competitors of D. frontalis were obtained. Collection of parasites, predators, and Ips competitors were made. Six lots of 12 logs each were collected in this study at approximately four month intervals, over a period of two years from the epizootic at the Ex-Hacienda Manzanilla, Puebla. The two year collection period began about a year after the epizootic started and terminated with its collapse. During the

laboratory chemical control experiments, parasites, predators, and Ips sp. that emerged from barrels (Figs. 41,42) containing treated logs were collected (App. 22-33).

The relative abundance of D. frontalis and Ips sp. is shown at the time the test logs were brought into the laboratory in each trial (App. 15). The emergence of D. frontalis, Ips sp., the parasites, and predators, at approximately four intervals, are compared in Appendix 16. The mortality differences were probably caused by intraspecific and interspecific competition between bark beetles which occurred between sampling and emergence.

The results show a cyclical increase and decrease in the number of Ips during Trials 1-6. The data may be misleading, since the logs were selected from portions of the tree bole containing large numbers of D. frontalis. The Ips were found mainly in the crown area of the trees during Trials 1 and 2. In Trials 3-5 the Ips sp. attacked the entire tree trunk to the ground line. Therefore, there was a much larger population of Ips in selected field logs during Trials 3-5, than was indicated by the data. No Ips emerged in Trials 1 and 6. The Ips have a shorter life cycle and infested the bark more rapidly and thoroughly than D. frontalis. Presumably, interspecific competition for space and food produced the decline of D. frontalis. Since the Ips beetles were dependent upon D. frontalis to initiate the attack on a tree and produce suitable host

material, they in turn declined as D. frontalis beetles were reduced in numbers, as shown in Trials 5 and 6 (App. 16).

Since logs that contained D. frontalis were always selected, the figures may again be misleading. For Trial 6, only about 10 infested trees remained in the forest area from which logs were collected. Hundreds of trees were available for Trial 1 and 5, and thousands of trees for Trials 3 and 4. D. frontalis beetles continue their attacks on each tree until it is heavily infested before attacking other trees in the vicinity, regardless of the numbers of uninfested trees available.

The epizootic at Puebla started about mid 1962, although the beetles were said to have been enzootic in the area for many years.[3] The beetles rapidly increased in 1963 and Ips bonanseai and Ips cribricollis were distributed in the crown portion of the trunk and the basal section of the branches while D. frontalis infested bark occurred on the main trunk from the ground level up into the lower crown portion. D. valens was abundant from a little above the ground level down into the roots.

Beginning in the spring of 1964 the Ips population that was concentrated in the crown and thinner bark regions increased until it covered most of the main trunk. By mid 1964, all trees killed by D. frontalis had Ips sp. distributed over the entire trunk. In the fall of 1964 the epizootic declined rapidly and only a few trees

contained D. frontalis and D. valens. No Ips were observed in any of the attacked trees at that time.

When abundant, the Ips sp. attacked trees at the same time as D. frontalis or within a day after. When the bark was removed one or two weeks after the attack, the Ips galleries were evident and the galleries of both bark beetles overlapped. The frass and other materials that the Ips sp. had pushed out of the D. frontalis galleries were evident and many eggs and the larvae of D. frontalis were presumably destroyed and starved in this process. The Ips competition resulted in the decline of D. frontalis epizootic. Since the Ips sp. were secondary attackers, they inturn declined because the primary insect, D. frontalis, was not available to make the initial attack. This appeared to be the end of the epizootic.

In December 1964 the few D. frontalis that were left concentrated their attacks on about 10 large overmature trees. Older or weaker trees were successfully attacked in the enzootic stage while young, vigorous trees were not. Surrounding the older trees which had been attacked were younger trees with no evidence of attack.

Coyne[10] reported that Ips cribricollis and Ips lecontei were abundant during the declining stage of the recent epizootic of D. frontalis in Honduras. This epizootic began in 1962 and declined in late 1965 due to natural causes (Coyne[11]). The extent of competition

between D. frontalis and Ips sp. was not described.

Parasites were abundant in Laboratory Trials 4-6 (App. 16). Over 95% of the parasites in these trials were Medetera aldrichii Wheeler (Diptera:Dolichopodidae). The eggs were laid on the bark surface and the parasitic larvae searched out their host. The majority of the flies emerged soon after the adult beetles emerged. Therefore, host preference seems to be for the pupal stage of the bark beetle. The decline of the epizootic at Puebla seemed to be produced primarily by competition with Ips sp., but the high numbers of M. aldrichii probably aided the decline and the final termination of the epizootic.

Two other parasites, Tomicobia tibialis Ashm. and Cecidostiba sp. (Hymenoptera:Pteromalidae), were also numerous (Table 8). Both of these species attacked bark beetle larvae and pupae. Tomicobia sp. were also collected in large numbers in Honduras.[10]

A dipteron in the family Lonchaeidae was collected emerging from the bark in large numbers in Mexico, but its habits are unknown.

The only predator that was collected in large numbers was the coleopteron Enoclerus sphegens (Cleridae), which was predatory in the larval and adult stages upon all stages of the bark beetles. Other predators known in Mexico and Honduras are listed in Table 9. The larvae of the clerid predators search for prey in both the adult and

larval galleries of D. frontalis and the Ips sp. When they encounter their prey in the galleries they immediately pierce the host. Adult clerids fed mainly upon bark beetle adults on the bark surface.

Ten different mite species were collected in Mexico (Table 10), and one of these was also collected in Honduras.[10] Several of the mites may be predators, but a Tarsonemus sp. (Tarsonemidae) which feeds on eggs only is probably the most important predator of the group. Moser[12] reported a Tarsonemus sp. in Honduras which may become numerous enough on the adult beetles to prevent locomotion, reproduction, and flight. The mites observed on D. frontalis in Mexico varied considerably in number; but no impairment if the life functions was observed.

Summary

Bark beetles of the genus Dendroctonus are the most destructive group of insects to forest trees in North America. D. frontalis alone is the most important forest pest in Honduras, Mexico, and southeastern United States. Fifteen generations of the beetles in the recent epizootic in Honduras covered over 5,000,000 acres and destroyed more than 11 million trees during the first 18 months.

Epizootics usually begin on weakened trees and spread to healthy trees. Within approximately two years the epizootics in Mexico and Honduras began to collapse.

Final collapse may occur in the third or fourth year due to natural factors, such as parasites and predators. Parasites and predators aid in control of D. frontalis, however, Ips sp. were observed in Mexico to cause a collapse of an epizootic due to interspecific competition for food and space.

Time is the most important factor in control. Many trees can be killed over the three to four year period of an epizootic. The wood deteriorates due to fungi and trees become valueless in one year. Speed of control is primary, and the cost secondary, to prevent the spread of the beetles to other trees.

Laboratory and field experiments were conducted using various concentrations of BHC gamma isomer, Malathion, EDB, and carbaryl insecticides. The laboratory experiments included topical applications of BHC and Malathion to larvae and adults and the application of all insecticides to the bark of infested logs which were placed in barrels to trap the emerging brood of adults. The field experiments were conducted with standing infested trees in the epizootic area.

Experiments conducted in the laboratory with water alone as the diluent for the insecticides were less effective than those in which diesel oil and water were the diluents. BHC was much more effective when diluted in water than were the other insecticides.

The formulation with 25% or more diesel oil in

water as an emulsion greatly increased the effectiveness of all insecticides. Beetles were killed in all stages since the oil carrying the insecticide penetrated the bark. A test with diesel oil alone produced no mortality of the beetles in the logs.

BHC produced the best results in all tests conducted in the laboratory and field. The tests with logs enclosed in barrels gave mortalities above 90% for concentrations between 0.025 and 1.50% gamma isomer content. Some fumigant action from BHC probably occurred in the barrels. This was evidenced by mortality of aphids on plants placed in the barrels. The amount of fumigant action was not known. The computed LD_{95} for BHC ranged between 0.07140-0.07183% gamma isomer content. Topical applications of 1.5 ml of BHC with concentrations between 0.0012 and 0.1000 of the gamma isomer were tried. The LD_{50} from these applications for larvae and adults were respectively 0.068 and 0.0076% gamma isomer content calculated on probability paper. The field tests with BHC gave mortalities above 97% of all concentrations between 0.50 and 2.50% gamma isomer, except for one 88% mortality recorded at the low 0.50% concentration. The LD_{90} for the field test, from the probability paper, was 0.042% gamma isomer concentration.

Malathion produced the second best results and was only slightly less toxic than BHC in the laboratory and field. The tests with logs enclosed in barrels yielded

mortalities above 90% for concentrations between 0.25 and 1.50%. The computed LD_{95} ranged between 0.3503-0.3511%. The topical malathion tests were similar to BHC in toxicity results and yielded an LD_{50}, from probability paper, at 0.084% and 0.0074% for larvae and adults. The field tests with malathion produced mortalities above 91% for all concentrations between 0.50 and 2.50%, except for a 70% and 84% mortality at 0.50 and 2.50% concentrations. The LD_{90} for the field test from probability paper was 0.45% concentration.

Carbaryl was the next most effective insecticide tried, but proved to have a much reduced toxicity when compared to BHC and malathion in tests conducted both in the laboratory and in the field. The tests with logs enclosed in barrels produced mortalities above 90% for concentrations between 1.75 and 3.00%. The computed LD_{95} ranged between 2.624-2.643%. The field tests with carbaryl yielded mortalities from 75 to 99% with concentrations between 1.50 and 4.00%. The LD_{90} for the field test, working from probability paper, was of 2.38% concentration.

The toxicity of EDB was very similar to carbaryl. The tests with logs in closed barrels produced mortalities above 88% at concentrations between 1.50 and 3.00%. The computed LD_{95} ranged between 2.106 and 2.107%. The field tests with EDB yielded mortalities of 0.0% for 1.00% concentration and between 48 and 100% for 4.00% concentration.

The LD_{90} for the field tests, working from probability paper, was 2.60% concentration.

The mechanical control and salvage operations observed in Mexico were not successful. The majority of the control of the epizootics came from natural enemies. The control operations were similar to harvesting operations except that the bark was burned. The speed of the operation was reduced by: trees that were attacked but not marked for cutting; not cutting trees recently attacked; insufficient manpower; and lack of modern equipment such as chain saws.

The associated bark beetles, Ips bonanseai and Ips cribricollis, were found to infest the trees below the crown portion of the trunk during the epizootic. Results of the four insecticide treatments were recorded when Ips sp. were abundant in the logs cut for the tests with D. frontalis. All insecticides except malathion produced over 90% average mortality of Ips sp. at all concentrations tried. At the lowest concentration, Malathion produced only 87% average mortality.

The parasites of D. frontalis and Ips sp. suffered over 90% average mortality from all four insecticides at all concentrations tested. The clerid predators suffered over 83% average mortality from all four insecticides at all concentrations tested.

Conclusions

The control of Dendroctonus frontalis Zimm. is necessary in Mexico to prevent the destruction of timber, especially during epizootics. The bark beetles usually appear in different size epizootics and kill many trees, with a resultant collapse of the epizootic due to natural causes in three to four years.

Time is the most important factor in controlling an epizootic in this bark beetle. The possibilities of controlling the insect in the early stages of an epizootic appears to be feasible if detection and action is accomplished with organization and speed. The economic loss of timber can be greatly reduced by early control of bark beetle epizootics.

Mechanical control by harvesting the attacked timber and burning the infested bark in Mexico was not successful. This was due mainly to lack of modern equipment, organization, and the slow speed at which the operation was carried out.

Chemical control of bark beetle epizootics, especially in the early stages, appears practical and economically feasible. The trees can be sprayed when first attacked and standing, thereby saving the time involved to have the trees marked for cutting by Federal Foresters as required by law. Also time would be saved from the actual felling of the trees before spraying operations. The

chemicals and pumps can be transported to the field by burros or vehicles. If water is located near the epizootic, transportation costs can be reduced.

Application of insecticides in water alone was not successful. The formation of emulsions with 25% diesel oil, water, and Triton X-100 emulsifier proved to give effective penetration of the bark. Diesel oil alone was not toxic to the beetles.

The insecticides tested in the laboratory and field were the gamma isomer of BHC, malathion, EDB, and carbaryl. In the laboratory tests upon logs, topical application of larvae and adults, and field trials, BHC proved to be the most toxic insecticide to D. frontalis. Concentrations of 0.50% gamma isomer of BHC or more in 25% diesel oil are recommended in field applications against the beetle. Malathion, which showed slightly less toxicity, could probably also be used at concentrations of 0.50% or more with 25% diesel oil for field applications against the beetle.

EDB and carbaryl are not recommended for control purposes against the bark beetle. This is because 90% mortality or above can only occur at a very high concentration. Results are somewhat irregular, and the insecticides are expensive to purchase. Monthly field checks should be required to locate trees freshly attacked by any beetles missed in the spray control operations.

The toxicity, persistence, and possible fumigant

action of BHC was an important advantage over the other insecticides. BHC seems like the insecticide to use in Mexico since it is very effective, relatively cheap, and formulated in Mexico. Malathion was slightly less effective for control, but may prove to be suitable because of its low residual effect.

The natural decline of an epizootic observed in Mexico near Puebla was primarily caused by interspecific competition with Ips sp. for food and space. Parasites, predators and man aided the epizootic collapse, but the Ips sp. migrated as they increased in abundance from their normal location in the crown portion of the trunk to cover the entire tree trunk. After the reduction in numbers of the primary beetle, D. frontalis, the secondary Ips beetles succeeded it with an increased amount of competition. The collapse of D. frontalis occurred over a span of about five months.

Footnotes

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TABLES

TABLE 1. Average number of days for development of Dendroctonus valens at different constant temperatures. The numbers represent the minimum developmental time for the first insect observed in the sandwiches to moult to the next instar or stage. Data taken from Appendix 3-7.

Instar & Stage	Temperature C. 8.5	15.0	20.0	25.0	30.0
I	27.0	18.2	13.1	9.3	7.0
II	27.0	11.2	6.1	4.4	7.1
III	11.0	14.7	13.6	10.0	9.1
IV	35.5	13.3	13.6	11.3	11.8
V	32.0	51.0	36.5	25.0	28.0
VI	114.5	18.0	----[b]	19.1	18.2
Total Days Larvae	247.0	126.4	82.9	79.1	79.6
Pupae	-----[a]	21.5	10.0	11.2	8.1
Callow Adult	-----	15.4	11.0	11.3	9.1
Total Days Larvae to Adult	247.0	163.2	104.0	104.5	97.0

[a]Experiment terminated before completion of development.

[b]No Data.

TABLE 2. Average number of days for development of Dendroctonus valens at different constant temperatures. The numbers represent the duration of any instar or stage. Data taken from Appendix 3-7.

Instar & Stage	Temperature C. 8.5	15.0	20.0	25.0	30.0
I	64.0	35.3	27.2	20.1	19.0
II	51.5	28.7	26.1	19.5	19.2
III	76.0	34.2	26.3	23.4	24.2
IV	57.5	38.3	24.1	25.0	20.6
V	61.5	70.0	46.2	41.1	38.0
VI	114.5	21.0	----[b]	24.1	21.0
Total Days Larvae	425.0	220.7	149.9	153.2	140.7
Pupae	-----[a]	31.2	19.1	16.2	14.2
Callow Adult	-----	18.2	18.0	16.1	16.0
Total Days Larvae to Adult	425.0	269.8	187.0	185.5	170.9

[a]Experiment terminated before completion of development.

[b]No data.

TABLE 3. Development of Dendroctonus frontalis in logs held at 15 C. The data were recorded on alternate days after opening new bark samples to expose the insects.

Days After Attack	Temp. Once Daily C	Log Group No.	No. of Family Gall. Opened	Adult Galleries Ave. Length Cm	Adult Galleries Tot. No. Eggs	Adult Galleries Ave. Per Gall.	Total No. of Lar. Only	Ave. Per Lar. Fam.	No. of Live Insects Developed
1	16.1	2	10	1.5	0	-	0	-	0
3	15.8	2	15	2.8	0	-	0	-	0
5	15.8	2	10	6.8	14	1.4	0	-	14
7	15.8	2	14	9.3	39	2.8	0	-	39
9	16.0	2	15	10.5	65	4.3	0	-	65
11	15.8	2	13	14.3	63	4.8	0	-	63
13	15.9	2	12	19.0	74	6.2	0	-	74
15	16.0	2	10	19.5	44	4.4	0	-	44
17	15.2	2	11	16.3	128	11.6	27	2.4	155
19	14.8	2	12	21.4	83	6.9	62	5.2	145
21	14.8	2	10	27.5	21	2.1	83	8.3	104
23	14.8	1	12	26.8	8	0.7	299	19.1	237
25	15.0	2	14	28.5	53	3.8	189	20.0	242
27	15.3	2	14	38.1	0	-	342	24.4	342
29	14.8	2	13	40.6	0	-	344	26.5	344
31	15.0	2	13	41.7	0	-	337	25.9	337
33	15.2	3	5	48.6	6	1.2	136	28.4	142
35	15.7	3	13	47.1	0	-	435	33.5	435
37	15.9	3	5	46.6	0	-	162	32.4	162
39	16.0	3	5	53.4	0	-	168	33.6	168
41	16.0	3	5	45.6	0	-	172	34.4	172
43	15.7	3	5	57.4	0	-	176	35.2	176
45	16.3	3	-[a]	-	0	-	240	-	240
47	15.6	3	-	-	0	-	238	-	238
49	15.0	3	-	-	0	-	215	-	215
51	14.0	3	-	-	0	-	246	-	246
53	13.2	3	-	-	0	-	248	-	248
55	13.4	3	-	-	0	-	210	-	210
57	14.7	3	-	-	0	-	180	-	180
59	15.5	3	-	-	0	-	98	-	100
61	15.2	3	-	-	0	-	100	-	100
63	-	1+3	-	-	0	-	200	-	200
65	-	1	-	-	0	-	100	-	100
67-75	15.8[b]	1	-	-	0	-	432	-	500
77-85	-	1	-	-	0	-	135	-	505
87-95	-	1	-	-	0	-	120	-	500
97-105	-	1	-	-	0	-	82	-	500
107-115	-	1	-	-	0	-	29	-	500
117-123	-	1	-	-	0	-	6	-	400
125-131	-	1	-	-	0	-	0	-	400

[a]Several galleries opened for each examination.

[b]Temperature continued at same level as determined by occasional measurements from 69 to 131 days after attack.

TABLE 4. Development of Dendroctonus frontalis in logs held at 15 C. The date were recorded on alternate days after opening new bark samples to expose the insects. The numbers represent the percentage of each stage including egg that was present on the day sampled.

Days After Attack	Larvae-Instars				Pupae	Callow Adult	Adults	
	I	II	III	IV			Insects	Exit Holes
17	17.4	-	-	-	-	-	-	-
19	42.8	-	-	-	-	-	-	-
21	79.8	-	-	-	-	-	-	-
23	96.6	-	-	-	-	-	-	-
25	77.3	0.8	-	-	-	-	-	-
27	11.7	88.3	-	-	-	-	-	-
29	6.7	77.0	16.3	-	-	-	-	-
31	-	78.6	21.4	-	-	-	-	-
33	19.7	66.9	9.2	-	-	-	-	-
35	1.1	13.6	83.4	1.9	-	-	-	-
37	0.6	10.5	88.9	-	-	-	-	-
39	-	29.2	66.7	4.2	-	-	-	-
41	-	2.9	92.4	4.7	-	-	-	-
43	-	1.7	75.6	22.7	-	-	-	-
45	-	21.2	32.1	46.7	-	-	-	-
47	1.8	14.3	46.1	37.8	-	-	-	-
49	-	12.5	42.8	44.7	-	-	-	-
51	-	9.0	34.1	56.9	-	-	-	-
53	-	9.7	40.3	50.0	-	-	-	-
55	-	7.6	40.5	51.9	-	-	-	-
57	-	4.4	40.6	55.0	-	-	-	-
59	-	8.0	42.0	48.0	2.0	-	-	-
61	-	12.0	43.0	45.0	-	-	-	-
63	-	14.0	40.5	45.5	-	-	-	-
65	-	-	45.0	55.0	-	-	-	-
67	3.0	19.0	40.0	38.0	-	-	-	-
69	-	1.0	42.0	41.0	16.0	-	-	-
71	-	-	34.0	61.0	5.0	-	-	-
73	-	-	30.0	59.0	11.0	-	-	-
75	-	-	18.0	46.0	30.0	6.0	-	-
77	-	-	15.0	21.0	44.0	20.0	-	-
79	-	-	8.0	13.0	57.0	22.0	-	-
81	-	-	2.0	8.6	56.1	25.7	7.6	-
83	-	-	15.0	21.0	48.0	12.0	4.0	-
85	-	-	13.0	17.0	39.0	25.0	6.0	-
87	-	-	11.0	16.0	48.0	18.0	7.0	-
89	-	-	4.0	10.0	19.0	23.0	44.0	-
91	-	-	2.0	5.0	15.0	20.0	58.0	-
93	-	-	13.0	24.0	23.0	16.0	24.0	-
95	-	-	11.0	24.0	15.0	15.0	35.0	-
97	-	-	10.0	20.0	24.0	19.0	27.0	-
99	-	-	-	12.0	14.0	5.0	33.0	36.0
101	-	-	-	6.0	21.0	11.0	37.0	25.0
103	-	-	-	8.0	14.0	8.0	35.0	35.0
105	-	-	11.0	16.0	13.0	7.0	21.0	32.0
107	-	-	-	6.0	5.0	4.0	21.0	64.0
109	-	-	-	6.0	6.0	3.0	11.0	74.0
111	-	-	-	9.0	5.0	7.0	11.0	68.0
113	-	-	-	8.0	5.0	5.0	9.0	73.0
115-123	-	-	-	1.0	1.0	3.0	1.0	94.0
125-131	-	-	-	-	-	-	-	100.0

TABLE 5. Development of Dendroctonus frontalis in logs held at 26 C. The data were recorded on alternate days after opening new bark samples to expose the insects.

Days After Attack	Temp. Once Daily C	Log Group No.	No. of Family Gall. Opened	Adult Galleries Ave. Length Cm	Adult Galleries Tot. No. Eggs	Adult Galleries Ave. Per Gall.	Total No. of Lar. Only	Ave. Per. Lar. Fam.	No. of Live Insects Developed
1	25.5	15	5	2.0	0	-	0	-	0
3	26.5	15	6	6.5	9	1.5	0	-	9
5	25.5	11	5	4.8	5	1.0	0	-	5
7	26.8	15	10	7.7	22	2.2	0	-	22
9	27.5	11	5	3.4	4	0.8	0	-	4
11	27.0	15	10	7.6	40	4.0	10	1.0	50
13	25.5	15	10	16.3	45	4.5	34	3.4	79
15	25.5	15	10	16.1	46	4.6	32	3.2	78
17	25.7	15	10	18.6	47	4.7	21	2.1	68
19	25.0	15	13	22.8	65	5.0	50	3.8	115
21	25.5	15	10	21.6	52	5.2	54	5.4	106
23	25.8	16	10	49.9	58	5.8	106	10.6	164
25	25.8	16	10	41.8	40	4.0	90	9.0	130
27	25.3	16	5	54.0	31	6.2	64	12.0	95
29	26.2	16	5	43.0	24	4.8	48	9.6	72
31	25.9	16	5	39.0	22	4.5	39	7.8	61
33	25.7	16	5	51.0	20	4.0	48	9.6	68
35	26.0	16	5	39.6	12	2.4	35	7.0	47
37	25.8	16	4	42.0	9	2.2	24	6.0	33
39	25.8	14	6	56.2	0	-	199	33.1	199
41	25.2	14	5	56.0	0	-	100	20.0	100
43	25.5	14	5	51.0	0	-	100	20.0	100
45	25.2	14	5	53.2	0	-	100	20.0	100
47	25.8	14	5	29.0	0	-	4	0.8	4
49	25.8	14	5	-	0	-	0	-	0
51	25.8	12	5	30.2	0	-	98	19.5	100
53	25.2	12	-[a]	-	0	-	50	-	100
55	26.0	12	-	-	0	-	9	-	100
57	26.0	12	-	-	0	-	43	-	100
59	25.9	11	-	-	0	-	12	-	100
61	25.5	11	-	-	0	-	10	-	100
63	26.0	11	-	-	0	-	73	-	100
65	26.2	11	-	-	10	-	88	-	100
67	26.0	10	-	-	0	-	21	-	100
69	25.8	10	-	-	0	-	21	-	100
71-77	25.1	9	-	-	0	-	89	-	400
79-87	25.8	8	-	-	0	-	71	-	500
89-95	25.6	7	-	-	0	-	12	-	400
97-107	26.2	6	-	-	0	-	94	-	600
109-119	25.6	7,5,4	-	-	0	-	0	-	600

[a]Several galleries opened for each examination.

TABLE 6. Development of Dendroctonus frontalis in logs at 26 C. The data were recorded on alternate days after opening new bark samples to expose the insects. The numbers represent the percentage of each stage including egg that was present on the day sampled.

Days After Attack	Larvae-Instars				Pupae	Callow Adult	Adults	
	I	II	III	IV			Insects	Exit Holes
11	20.0	-	-	-	-	-	-	-
13	43.0	-	-	-	-	-	-	-
15	41.0	-	-	-	-	-	-	-
17	30.9	-	-	-	-	-	-	-
19	43.5	-	-	-	-	-	-	-
21	43.4	7.6	-	-	-	-	-	-
23	54.1	7.0	0.5	-	-	-	-	-
25	58.5	10.7	-	-	-	-	-	-
27	28.4	39.0	-	-	-	-	-	-
29	34.7	32.0	-	-	-	-	-	-
31	32.8	31.1	-	-	-	-	-	-
33	41.2	29.4	-	-	-	-	-	-
35	38.3	36.2	-	-	-	-	-	-
37	33.3	39.4	-	-	-	-	-	-
39	5.0	36.2	51.8	7.0	-	-	-	-
41	4.0	21.0	59.0	16.0	-	-	-	-
43	2.0	25.0	48.0	25.0	-	-	-	-
45	-	19.0	60.0	21.0	-	-	-	-
51	-	14.0	55.0	29.0	2.0	-	-	-
53	-	5.0	22.0	29.0	2.0	9.0	10.0	24.0
55	-	-	3.0	6.0	17.0	8.0	26.0	40.0
57	-	-	20.0	23.0	15.0	8.0	12.0	22.0
59	-	-	6.0	8.0	12.0	7.0	20.0	47.0
61	-	-	3.0	7.0	8.0	4.0	9.0	69.0
63	-	2.0	39.0	32.0	5.0	6.0	6.0	10.0
65	9.0	30.0	28.0	21.0	2.0	-	-	-
67	-	-	10.0	11.0	14.0	12.0	15.0	38.0
69	-	-	8.0	13.0	18.0	10.0	15.0	36.0
71	-	-	5.0	12.0	9.0	8.0	13.0	53.0
73	-	-	25.0	30.0	12.0	10.0	5.0	18.0
75	-	-	-	13.0	12.0	3.0	5.0	67.0
77	-	-	-	4.0	8.0	8.0	4.0	76.0
79	-	-	23.0	40.0	7.0	-	3.0	27.0
81	-	-	-	5.0	4.0	4.0	10.0	77.0
83	-	-	-	2.0	2.0	2.0	2.0	92.0
85	-	-	-	-	-	-	1.0	99.0
87	-	-	-	1.0	2.0	-	-	97.0
89	-	-	-	7.0	5.0	2.0	-	86.0
91	-	-	-	5.0	3.0	4.0	2.0	86.0
93	-	-	-	-	1.0	-	-	99.0
95	-	-	-	-	-	-	-	100.0
97	-	-	-	8.0	6.0	3.0	7.0	76.0
99	-	-	-	15.0	6.0	1.0	5.0	73.0
101	-	-	-	17.0	10.0	6.0	12.0	55.0
103	-	-	2.0	24.0	8.0	-	6.0	60.0
105	-	-	-	22.0	28.0	6.0	17.0	27.0
107	-	-	-	6.0	12.0	6.0	11.0	65.0
109-119	-	-	-	-	-	-	-	100.0

TABLE 7. Development of Dendroctonus frontalis in logs at 15 and 26 C in days. The data represent the duration (in days after original attack) that different stages and instars were observed, the peak abundance, and minimum developmental time for the first insect that was observed to moult in the samples. Data taken from Tables 3-6.

	15 C			26 C		
	Duration	Peak Abundance	Minimum Developmental Time	Duration	Peak Abundance	Minimum Developmental Time
Egg	5-33	17	12	3-37	19	8
Larval Instar I	17-67	23	8	11-65	25	10
II	25-69	27	4	21-65	27-39	2
III	29-105	41	6	23-103	45	16
IV	35-123	51-73	24	39-107	51-63	12
Larval Period	17-123			11-107		
Pupae	59-123	81	16	51-107	55-69	2
Callow Adults	75-123	77-97	6	53-107	67	0
Adults	81-125	91	18	53-107	55-71	0
Exit Holes	99-plus			53-plus		
Generation	81-125			53-107		

TABLE 8. The known insect parasites of Dendroctonus frontalis in North America (Hopkins, 1893; Fiske, 1908; Boving and Champlain, 1921, Muesebeck, 1938; Chamberlin, 1939; Hetrick, 1940; Fronk, 1947; Perry, 1951; Muesebeck et al., 1951,1958; Dixon and Osgood, 1961; Coyne, 1966[11]; Rose, 1963-6 unpublished).

Parasitic Species	Stage of Host Parasitized
Diptera	
Ceratopogonidae	
Forcipomyia cilipes (Coq.)[2]	?
Forcipomyia texana (Long)[2]	?
Dolichopodidae	
Medetera aldrichii Wheeler[2]	lar., pup., adlt.
Lonchaeidae sp.[2]	lar. ?
Stratiomyiidae	
Microchrysa polita (L.)	lar.
Zabrachia sp.[2]	lar. ?
Hymenoptera	
Braconidae	
Bracon pissodis Ashm.	lar., pup.
Coeloides pissodis (Ashm.)	lar.
Compyloneurus (Bracon) mavoritus (Cress)	lar.
Dendrosoter sulcatus Meus.	lar.
Doryctes sp.	lar.
Ecphylus sp.[3]	lar.
Ecphylus (Sactopus) schwarzii (Ashm.)	lar.
Heydenia unica C. and D.	lar., pup.
Lochites sp.	lar., pup.
Spathius canadensis Ashm.	lar.
Rogas sp.[2]	lar. ?
Eupelmidae	
Lutnes sp.[2]	egg, lar., pup.
Ichneumonidae	
Asphragis sp.	?
Campoplex sp. (Phaedroctonus group)[3]	lar.
Hemitelini[2]	hyperparasite ?
Lissonota sp.[2]	?
Pteromalidae	
Amblymerus sp.[2]	lar., pup.
Cecidostiba sp.[2,3]	lar., pup.
Cecidostiba dendroctoni Ashm.	lar., pup.
Pachyceras sp.[1]	lar., pup.
Tomicobia sp.[1,3]	lar., pup.
Tomicobia tibialis Ashm.[2]	lar., pup.
Sphecidae	
Passaloecus sp.[2]	lar., pup.
Torymidae	
Liondontomerus (Lochites) sp.	lar.
Roptrocerus sp.[3]	lar., pup.
Roptrocerus (Pachyceras) eccoptogasteri Ratz.	lar., pup.

Known in Mexico--1--Perry, 1951, 2--Rose, 1963-6 unpublished.

Known in Honduras

3--Coyne, 1966[11].

TABLE 9. The known insect predators of Dendroctonus frontalis in North America (Hopkins, 1893; Fiske, 1908; Boving and Champlain, 1921; Chamberlin, 1939; Fronk, 1947; Perry, 1951; Moreno, 1954; Dixon and Osgood, 1961; Coyne, 1966[11]; Rose, 1963-6 unpublished).

Predator Species	Stage of Host Attacked
Coleoptera	
Cleridae	
Clerus elegans Bon.[2]	egg, lar., pup., adlt.
Clerus mexicanus Bon.[2]	egg, lar., pup., adlt.
Cymatodera sp. near Morosa (lec.)[1]	lar., adlt.
Enoclerus sp.[3]	lar., adlt.
Enoclerus quadriguttatus Oliv.	egg, lar., adlt.
Enoclerus sphegens F. (F.)[1,3]	egg, lar., adlt.
Enoclerus quadrisignatus var. nigripes Say	egg, lar., adlt.
Priocera castanea (Newman)	?
Thanasimus dubius (F.)	egg, lar., adlt.
Thanasimus formicarus	egg, lar., adlt.
Thanasimus nigriventris[1,2]	egg, lar., adlt.
Colydiidae	
Lasconotus sp.[3]	lar. ?
Elateridae	
Elaterid sp.	lar., pup. adlt.
Nitidulidae	
Epuraea alticola Sharp[3]	lar.
Glischrochilus lecontei Brown[3]	lar.
Ostomidae	
Temnochila sp.[2]	lar.
Temnochila virascens (F.)[1]	lar., pup. adlt.
Trogosita sp.[4]	lar., pup. ?
Staphylinidae sp.[3]	lar., pup. ?
Tenebrionidae	
Corticeus sp.[2,3,4]	lar. ?
Corticeus parallelus Melsh.[2]	lar. ?
Hypophloeus parallelus Melsh.	?
Hypophloeus cavus Lec.	?
Tenebroides collaris (Strum)	lar., pup., adlt.
Diptera	
Ceratopogonidae	
Forcipomyia cilipes (Coq.)[3]	?
Forcipomyia texana (Long)[3]	?
Dolichopodidae	
Medetera aldrichii Wheeler[3]	lar., pup., adlt.

TABLE 9--Continued

Predator Species	Stage of Host Attacked
Hemiptera	
Anthocoridae	
Anthocoris sp.	egg, lar.
Lyctocoris elongatus (Reuter)	egg, lar.
Scoloposcelia flavicornis (Reuter)	egg, lar.
Lepidoptera	
Cosmopterigidae sp.[3]	?
Neuroptera	
Hemerobiidae	
Sympherobius angustus (Bks.)[3]	lar.

Known in Mexico

1--Perry, 1951, 2--Moreno, 3--Rose, 1963-6 unpublished.

Known in Honduras

4--Coyne, 1966[11].

TABLE 10. Arthopods other than insects associated with *Dendroctonus frontalis* in Mexico.[14,16]

Species	Nature of Association
Acarina	
Acaridae	
(Histogaster arborsignum?) hypopi (= deutonymph)	attack lar.
Blattisocidae	
Asca sp.	?
Proctolelaps nr. dendroctoni	?
Proctolelaps nr. hypudaei	?
Proctolelaps nr. hystrix	?
Ereynetidae	
Ereynetoides scutulis	?
Parasitidae	
Eugamasus sp.	attack lar.
Pyemotidae	
Pyemotes sp.	attack lar.
Tarsonemidae	
Tarsonemus sp.[1]	attack eggs
Uropodidae	
Leiodinychus sp.	?
Tyedidae sp.	?
Pseudoscorpionida sp.	probably attack mites and Psocidae: Trichadenotecum (Loensia) sp.

Known in Honduras

1--Coyne, 1966[11].

TABLE 11. The expenditures and receipts per cubic meter harvested timber attacked by Dendroctonus frontalis in a mountainous pine forest near Nicolas Romero, Mexico. Data received from the Mexican Forest Service, Mexico, D.F.[3]

	Mex. Pesos	U. S. Dollars
Middle man pays forest owners	15.00	1.20
Truck transportation to a paper mill (70 miles)	45.00	3.60
Truck transportation of firewood (70 miles)	25.00	2.00
Labor for felling, peeling, bucking, splitting, and burning of the bark . . .	24.00	1.92
Transportation of paper wood and firewood by burro from stump to road (distance up to one mile)	10.00	0.80
Taxes to government (1) paperwood	5.00	0.40
(2) firewood	0.24	0.02
Taxes to Forestry Dept. (1) paperwood . . .	3.00	0.24
(2) firewood . . .	0.70	0.06
Taxes to Forest Research Institute	1.05	0.08
Taxes for reforestation	2.50	0.20
Total cost of operation	131.49	10.52
Money received for paperwood at factory . .	135.00	10.80
Money received for firewood in city	35.00	2.80

TABLE 12. The expenditures and receipts per cubic meter of harvested timber attacked by Dendroctonus frontalis in a pine plantation at Puebla, Mexico. Data received from the owner of the Ex-Hacienda Manzanilla, Puebla.

	Mex. Pesos	U. S. Dollars
Tractor and wagon for transportation of firewood	5.00	0.40
Tractor for skidding tree length logs .	10.00	0.80
Truck transportation of paper wood (90 miles)	45.00	3.60
Truck transportation of firewood (90 miles)	25.00	2.00
Labor for felling, peeling, bucking, and splitting	25.00	2.00
Labor for burning bark	2.00	0.16
Taxes to government (1) paperwood . . .	5.00	0.40
(2) firewood . . .	0.24	0.02
Taxes to Forestry Dept. (1) paperwood .	3.00	0.24
(2) firewood . .	0.70	0.06
Taxes to Forest Research Institute . . .	1.05	0.08
Taxes for reforestation	2.50	0.20
Total cost of operation	124.54	9.96
Money received for paperwood at factory	135.00	10.80
Money received for firewood in city . .	35.00	2.80

TABLE 13. The average percentage of mortality and the average number of emerged beetles of Dendroctonus frontalis from logs in the Laboratory Trials 2-6 treated with Insecticides.

Insecticides	Per Cent Active Ingredient															
	0.012	0.025	0.05	0.10	0.125	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00
	Per Cent Mortality																
BHC[a]	79.3	93.0	97.9	98.8	99.2	99.5	99.5	99.5	99.2		93.2						
Malathion					82.2	92.0	96.5	97.7	99.2		99.2						
EDB						0.0		29.1	83.5	88.7	95.5	94.9	95.4	88.0	97.2	98.4	
Carbaryl						59.1		63.2	58.2	71.4	92.5	96.9	97.5	96.0	98.0	99.7	
	Number Emerged[b]																
BHC[a]	361	104	34	11	9	10	9	8	6		30						
Malathion					210	86	46	34	6		7						
EDB						3154		1597	227	172	44	51	56	123	32	28	
Carbaryl						918		820	560	480	98	37	35	46	29	6	

[a]gamma isomer content.

[b]check average = 1452

TABLE 14. Computation table for fitting of BHC (gamma isomer) probit regression equation.

BHC % Active Ingredient (x100)	Log. Con. (X)	Chk. Ave. Total Insects (n)	Obser. Kill (r)	% Kill (p)	Emp. Probit	Prov. Probit (Y)	Wting Coeff. (w)	Work. Probit (y)	Weight (nw)
01.2	0.0792	1748	1387	79.3	5.81	5.85	.471	5.81	823.31
02.5	0.3979	1384	1276	92.2	6.41	6.35	.302	6.42	417.97
05.0	0.6990	1219	1185	97.2	6.88	6.85	.154	6.91	187.73
10.0	1.0000	1219	1208	99.1	7.33	7.35	.062	7.36	75.58
12.5	1.0969	1083	1074	99.2	7.33	7.33	.076	7.40	82.31
25.0	1.3979	1114	1104	99.1	7.33	7.33	.076	7.36	84.66
50.0	1.6990	1803	1790	99.3	7.33	7.33	.076	7.43	137.03
75.0	1.8751	1338	1330	99.4	7.33	7.33	.076	7.47	101.69
100.0	2.0000	2267	2261	99.7	7.33	7.33	.076	7.57	172.29
150.0	2.1761	2267	2237	98.7	7.33	7.33	.076	7.22	172.29

$\frac{1}{Snw} = 0.00044$ $\quad \bar{y} = 6.5984$ $\quad \bar{x} = 0.79382$ $\quad Sxx = 1340.019$

$Sxy = 1107.664$ $\quad Syy = 1090.118$ $\quad b = \frac{Snwxy - \bar{x}Snwy}{Snwx^2 - \bar{x}Snwx} = 0.8266$

$y = (\bar{y} - b\bar{x}) + bx = 5.85$ $\quad$ Variance $= \frac{1}{b^2}\left(\frac{1}{Snw} + \frac{(m-\bar{x})^2}{Snwx^2 - \frac{(Snwx)^2}{Snw}}\right) = mLD_{95}\ 0.000648$

$LD_{95} - m_1 = m - 1.96V$

$m_2 = m + 1.96V$

LD_{95} Fiducial limits with range from 0.07140 to 0.07183 %

TABLE 15. Computation table for fitting of malathion probit regression equation.

Mal. % Active Ingredient (x100)	Log. Con. (X)	Chk. Ave. Total Insects (n)	Obser. Kill (r)	% Kill (p)	Emp. Probit	Prov. Probit (Y)	Wting. Coeff. (w)	Work Probit (y)	Weight (nw)
12.5	1.0969	1249	1039	83.2	5.95	6.00	.439	5.96	548.31
25.0	1.3979	1249	1162	93.0	6.48	6.42	.302	6.47	377.20
50.0	1.6990	1453	1406	96.8	6.88	6.82	.180	6.85	261.54
75.0	1.8751	1249	1214	97.2	6.88	7.07	.131	6.90	163.62
100.0	2.0000	2267	2261	99.7	7.33	7.25	.076	7.57	172.29
150.0	2.1761	2267	2260	99.7	7.33	7.33	.076	7.57	172.29

$\frac{1}{Snw} = 0.000589\$$ $\quad \bar{y} = 6.62876$ $\quad \bar{x} = 1.53334$ $\quad Sxx = 246.235$

$Sxy = 372.840$ $\quad Syy = 585.271$ $\quad b = \frac{Snwxy - \bar{x}Snwy}{Snwx^2 - \bar{x}Snwx} = 1.524$

$y = (\bar{y} - b\bar{x}) + bx = 6.00$ $\quad$ Variance $= \frac{1}{b^2}\left(\frac{1}{Snw} + \frac{(m-\bar{x})^2}{Snwx^2 - \frac{(Snwx)^2}{Snw}}\right) = mLD_{95}\ 0.000254$

$LD_{95} = m_1 = m - 1.96V$

$m_2 = m + 1.96V$

LD_{95} fiducial limits with range from 0.3503 to 0.3511 %

TABLE 16. Computation table for fitting of EDB probit regression equation.

EDB % Active Ingredient (x100)	Log. Con. (X)	Chk. Ave. Total Insects (n)	Obser. Kill (r)	% Kill (p)	Emp. Probit	Prov. Probit (Y)	Wting. Coeff. (w)	Work Probit (y)	Weight (nw)
50.0	1.6990	2267	0	0					
100.0	2.0000	2267	670	29.6	4.48	4.88	.634	4.49	1437.28
125.0	2.0969	1338	1111	83.0	5.95	5.36	.601	5.88	804.14
150.0	2.1761	1803	1630	90.4	6.28	5.78	.503	6.20	906.91
175.0	2.2430	1114	1070	96.1	6.75	6.14	.405	6.54	451.17
200.0	2.3010	1083	1032	95.3	6.64	6.44	.302	6.63	327.07
225.0	2.3522	1219	1163	95.4	6.64	6.70	.208	6.68	253.55
250.0	2.3979	1219	1096	89.9	6.28	6.91	.154	5.80	187.73
275.0	2.4393	1384	1352	97.7	7.05	7.12	.110	6.99	152.24
300.0	2.4771	1748	1720	98.4	7.05	7.33	.076	7.12	132.85

$\frac{1}{Snw} = 0.0002149$ $\quad \bar{y} = 5.74181$ $\quad \bar{x} = 2.159033$ $\quad Sxx = 73.120$

$Sxy = 518.383$ $\quad Syy = 3716.382$ $\quad b = \frac{Snwxy - \bar{x}Snwy}{Snwx^2 - Snwx} = 5.457$

$y = (\bar{y}-b\bar{x}) + bx = 4.88$ $\quad Variance = \frac{1}{b^2}\left(\frac{1}{Snw} + \frac{(m-\bar{x})^2}{Snwx - (Snwx)^2}\right) = mLD_{50} = 0.0000129$

$mLD_{95} = 0.00001597$

$LD_{50}, LD_{95} = m_1 = m - 1.96V$

$m_2 = m + 1.96V$

Fiducial Limits
LD_{50} with range from 1.059 to 1.059 %
LD_{95} with range from 2.106 to 2.107 %

TABLE 17. Computation table for fitting of Carbaryl probit regression equation.

Carbaryl % Active Ingredient (x100)	Log. Con. (X)	Chk. Ave. Total Insects (n)	Obser. Kill (r)	% Kill (p)	Emp. Probit	Prov. Probit (Y)	Wting. Coeff. (w)	Work. Probit (y)	Weight (nw)
50.0	1.6990	2267	1349	59.5	5.25	5.01	.637	5.243	1444.070
100.0	2.0000	2267	1447	63.8	5.36	5.59	.558	5.334	1264.986
125.0	2.0969	1338	778	58.1	5.20	5.77	.503	5.084	673.014
150.0	2.1761	3605	1322	73.3	5.61	5.92	.471	5.586	1697.955
175.0	2.2430	2228	1016	91.2	6.34	6.05	.405	6.316	902.340
200.0	2.3010	3248	1046	96.6	6.88	6.16	.370	6.615	1201.760
225.0	2.3522	3658	1184	97.1	6.88	6.26	.336	6.701	1229.088
250.0	2.3979	3658	1173	96.3	6.75	6.35	.302	6.686	1104.716
275.0	2.4393	2768	1355	97.9	7.05	6.43	.302	6.800	835.936
300.0	2.4771	1748	1742	99.7	7.33	6.50	.269	6.987	470.212

$\frac{1}{Snw} = 0.0000923$ $\quad \bar{y} = 6.04817$ $\quad \bar{x} = 2.182424$ $\quad Sxx = 587.483$ $\quad Sxy = 1462.352$

$Syy = 4880.783$ $\quad b = \frac{Snwxy - \bar{x}Snwy}{Snwx^2 - Snwx} = 2.49390875$ $\quad y = (\bar{y} - b\bar{x}) + bx = 5.01$

$$\text{Variance} = \frac{1}{b^2}\left(\frac{1}{Snw} + \frac{(m-\bar{x})^2}{Snwx - \frac{(Snwx)^2}{Snw}}\right) = mLD_{50} = 0.00015635 \quad mLD_{95} = 0.0000753692$$

$LD_{50}, LD_{95} = m_1 = m - 1.96V$
$m_2 = m + 1.96V$

Fiducial Limits
LD_{50} with range from 0.5750 to 0.5758 %
LD_{95} with range from 2.642 to 2.643 %

TABLE 18. The average percentage of mortality and the average number of emerged beetles of Ips sp. from logs in the Laboratory Trials 3-5 treated with insecticidal applications.

Insecticides	Per Cent Active Ingredient													
	0.25	0.05	0.10	0.125	0.25	0.50	0.75	1.25	1.50	1.75	2.00	2.25	2.50	2.75
	Per Cent Mortality													
BHC[a]	96.8	98.3	98.4	99.0	99.4	100.0	100.0							
Malathion				87.4	96.3	94.5	98.8							
EDB								99.2	96.2	99.2	97.4	99.3	98.2	99.2
Carbaryl								96.3	98.2	97.8	97.9	96.1	98.6	99.2
	Number Emerged[b]													
BHC[a]	4	2	8	3	2	0	0							
Malathion				24	12	31	6							
EDB								2	14	5	23	7	7	1
Carbaryl Sevin								13	6	19	4	30	13	1

[a]gamma isomer content

[b]check average = 494

TABLE 19. The average percentage of mortality and the average number of emerged parasites of Dendroctonus frontalis and Ips sp. from logs in the Laboratory Trials 3-6 treated with insecticidal applications.

Insecticides	Per Cent Active Ingredient															
	0.012	0.025	0.05	0.10	0.125	0.25	0.50	0.75	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00
	Per Cent Mortality															
BHC[a]	95.6	99.3	99.8	99.6	99.2	100.0	100.0	100.0								
Malathion					90.0	94.1	99.0	97.8								
EDB									100.0	100.0	99.9	98.9	98.4	99.6	99.6	98.3
Carbaryl									94.1	94.1	96.0	99.2	99.7	99.3	99.3	99.6
	Number Emerged[b]															
BHC[a]	148	0	1	3	2	0	0	0								
Malathion					24	12	8	13								
EDB									0	0	3	4	16	4	4	17
Carbaryl									3	3	5	2	2	5	0	4

[a]gamma isomer content.

[b]check average = 451

TABLE 20. The average percentage of mortality and the average number of emerged Clerids of Dendroctonus frontalis and Ips sp. from logs in the Laboratory Trials 3-6 treated with insecticidal applications.

Insecticides	Per Cent Active Ingredient															
	0.012	0.025	0.05	0.10	0.125	0.25	0.50	0.75	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00
	Per Cent Mortality															
BHC[a]	100.0	98.5	95.5	90.7	96.4	90.1	100.0	100.0								
Malathion					88.4	98.6	98.3	95.0								
EDB									100.0	100.0	94.6	100.0	100.0	82.7	100.0	100.0
Carbaryl									91.2	87.1	93.3	100.0	96.3	92.3	93.1	97.0
	Number Emerged[b]															
BHC[a]	0	0	1	3	1	3	0	0								
Malathion					3	0	0	1								
EDB									0	0	1	0	0	5	0	0
Carbaryl									2	3	2	0	1	2	2	1

[a]gamma isomer content.

[b]check average = 27

TABLE 21. The average percentage of mortality of Dendroctonus frontalis from topical application of insecticides 48 hours after application. Each trial represents 3 replicates of 30 insects per concentration.

Per Cent Active Ingredient	BHC - (gamma isomer) Larvae Laboratory Trial 6	7	9	Average
0.0012	3.3	10.0	5.0	6.100
0.0037	10.0	20.0	10.0	13.333
0.01	16.7	15.0	20.0	17.233
0.03	23.3	65.0	20.0	36.100
0.1	33.3	70.0	75.0	59.433
Check	10.0	10.0	20.0	13.333

	Malathion - Larvae Laboratory Trial 6	7	9	
0.0012	10.0	15.0	25.0	16.666
0.0037	26.7	5.0	35.0	22.233
0.01	6.7	20.0	10.0	12.233
0.03	43.3	45.0	35.0	41.100
0.1	46.7	65.0	55.0	55.566
Check	0.0	10.0	45.0	18.333

	BHC - (gamma isomer) Adults Laboratory Trial 3	4	5	8	
0.0012	63.3	50.0	30.0	16.7	40.000
0.0037	40.0	40.0	30.0	36.7	36.675
0.01	53.3	33.3	53.3	73.3	53.300
0.03	76.7	46.7	73.0	86.7	70.775
0.1	93.3	73.3	80.0	90.0	84.150
Check	23.3	13.3	10.0	13.3	14.975

	Malathion - Adults Laboratory Trial 3	4	5	8	
0.0012	30.0	30.0	16.7	50.0	31.675
0.0037	36.7	23.3	40.0	63.3	40.825
0.01	26.7	50.0	46.7	46.7	42.525
0.03	73.3	60.0	83.3	90.0	76.650
0.1	70.0	93.3	100.0	96.7	90.000
Check	26.7	13.3	16.7	0.0	14.175

Table 22. The percentages of mortality of Dendroctonus frontalis in trees treated with insecticides with diesel oil in the field.

Diesel Oil %	Per Cent Active Ingredient 0.50	1.00	1.50	2.50	4.00
			BHC[a]		
25	98.1	97.1	100.0	99.3	
25	100.0	99.8	99.8	100.0	
37.5	98.1	96.5	99.8	99.8	
37.5	88.1	99.3	100.0	100.0	
50	97.1	98.6	100.0	100.0	
50	97.8	100.0	100.0	-----[b]	
			Malathion		
25	100.0	-----	98.6	96.5	
25	99.3	-----	99.3	96.5	
37.5	91.4	94.6	100.0	84.3	
37.5	70.4	100.0	100.0	100.0	
50	94.7	98.6	96.5	100.0	
50	100.0	100.0	98.6	96.5	
			EDB		
25		0.0	-----	68.3	-----
25		-----	-----	86.1	93.1
37.5		-----	-----	55.3	48.4
37.5		-----	82.1	71.1	72.2
50		0.0	-----	-----	100.0
50		0.0	-----	70.2	85.1
			Carbaryl		
25		82.1	-----	89.6	94.5
25		-----	-----	-----	93.6
37.5		68.6	98.5	-----	97.0
37.5		75.0	97.0	93.6	91.1
50		10.3	-----	91.1	74.6
50		32.7	97.0	79.8	87.5

[a]gamma isomer content.

[b]data missing, see text.

FIGURES

FIGURE 1. Developmental rate for different instars and stages of Dendroctonus valens. The probit graph represents the minimum developmental time for the first insect observed in the sandwiches to moult to the next instar or stage. Data taken from Appendix 1.

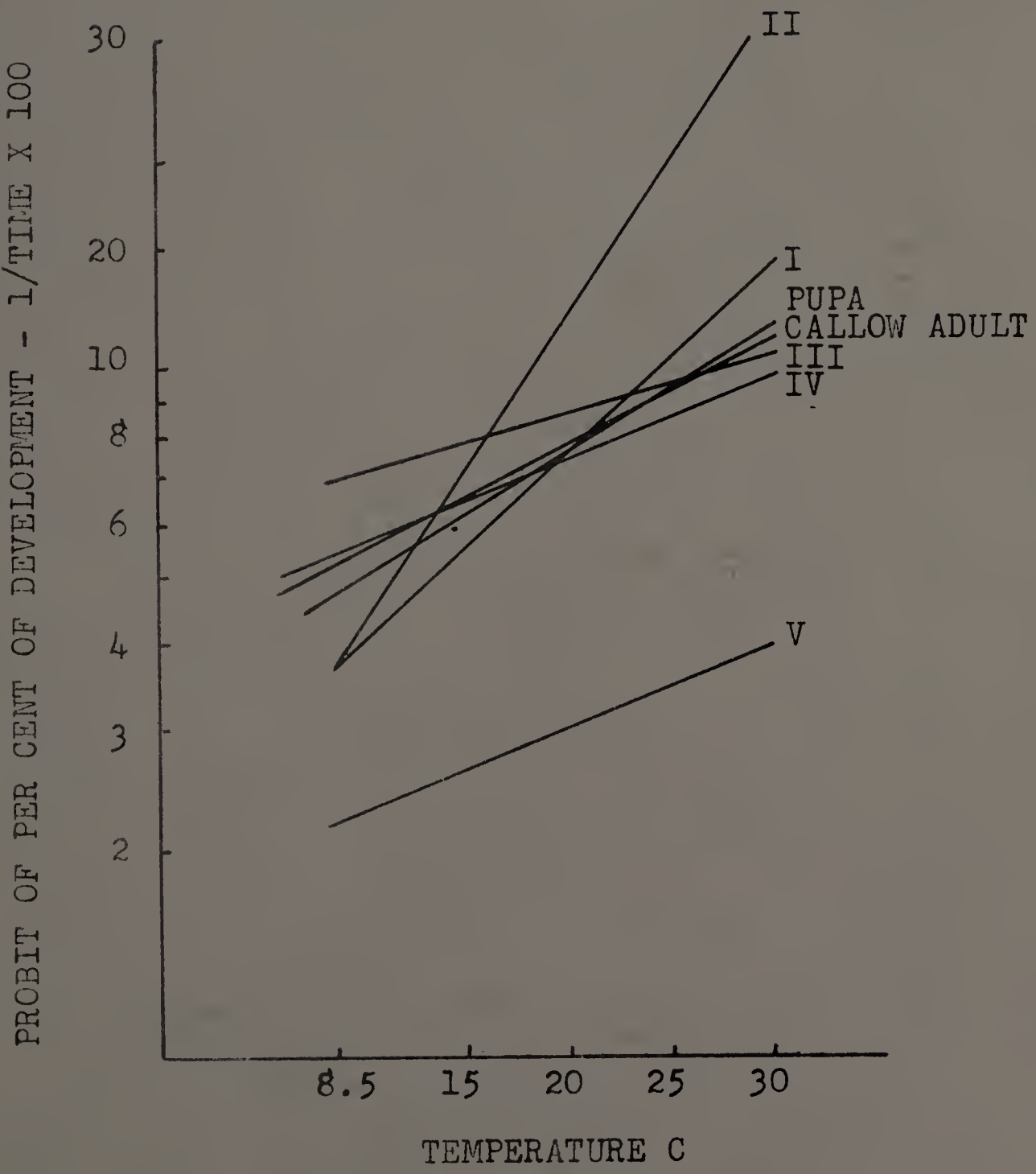


FIGURE 2. Developmental rate for different instars and stages of Dendroctonus valens. The probit graph represents duration of any instar or stage. Data taken from Appendix 2.

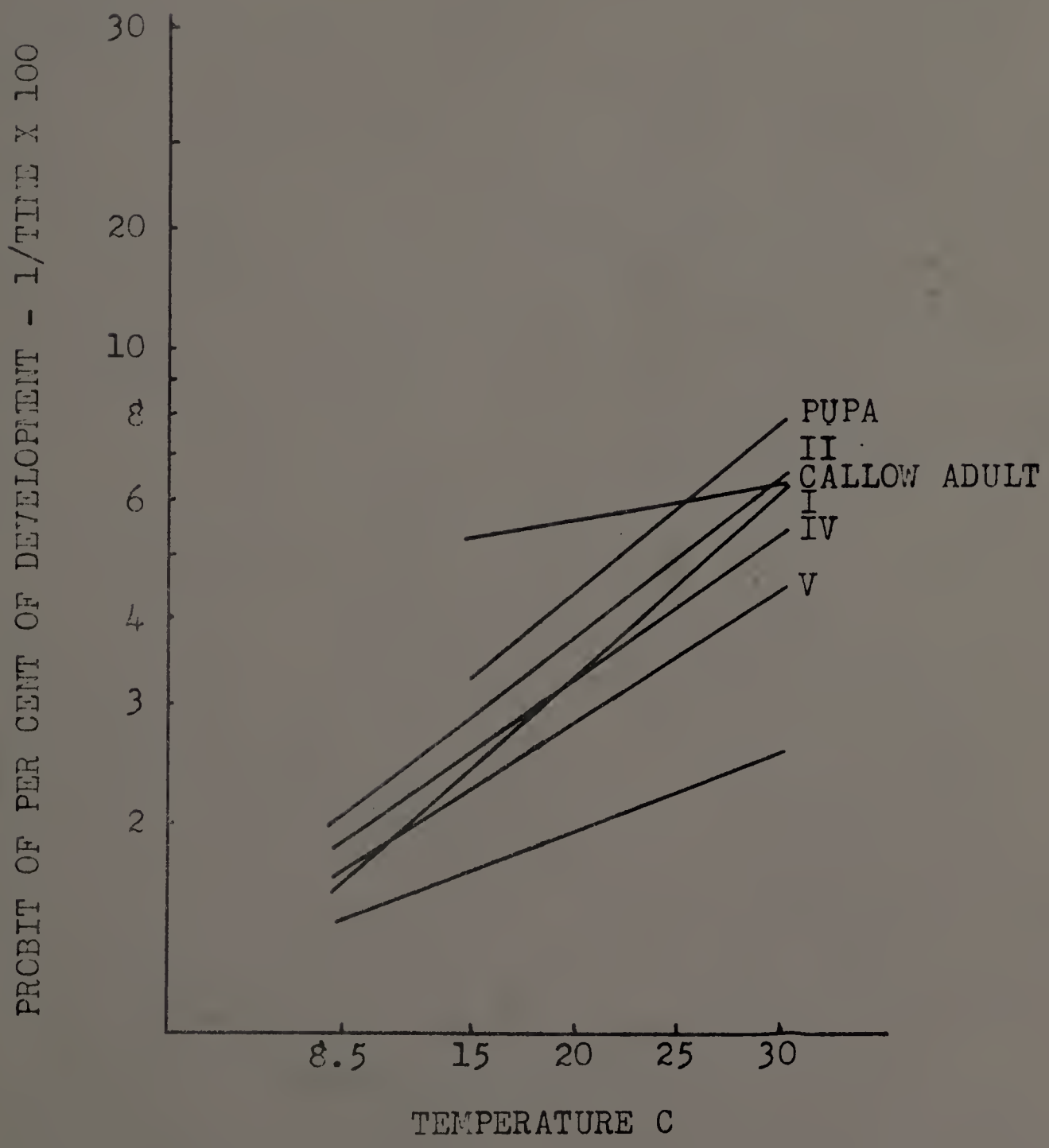
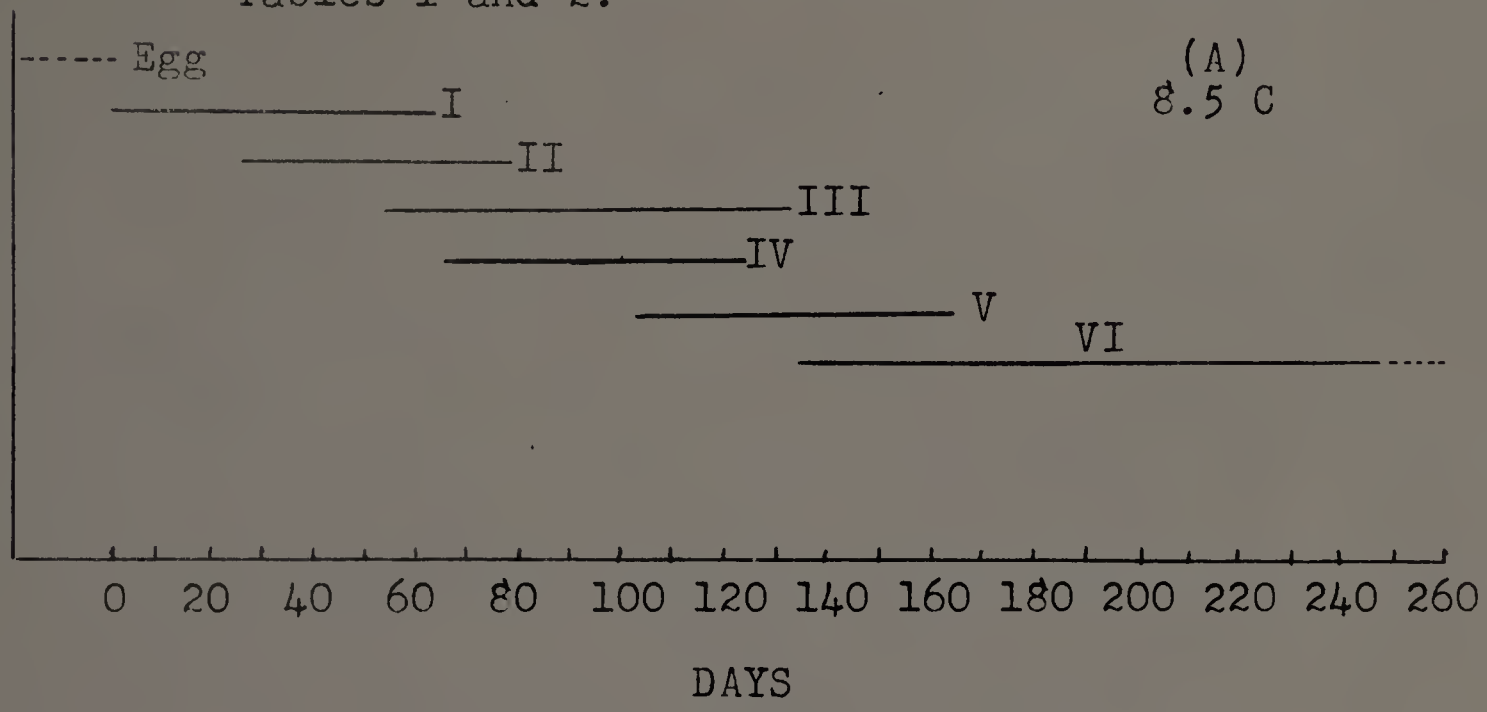
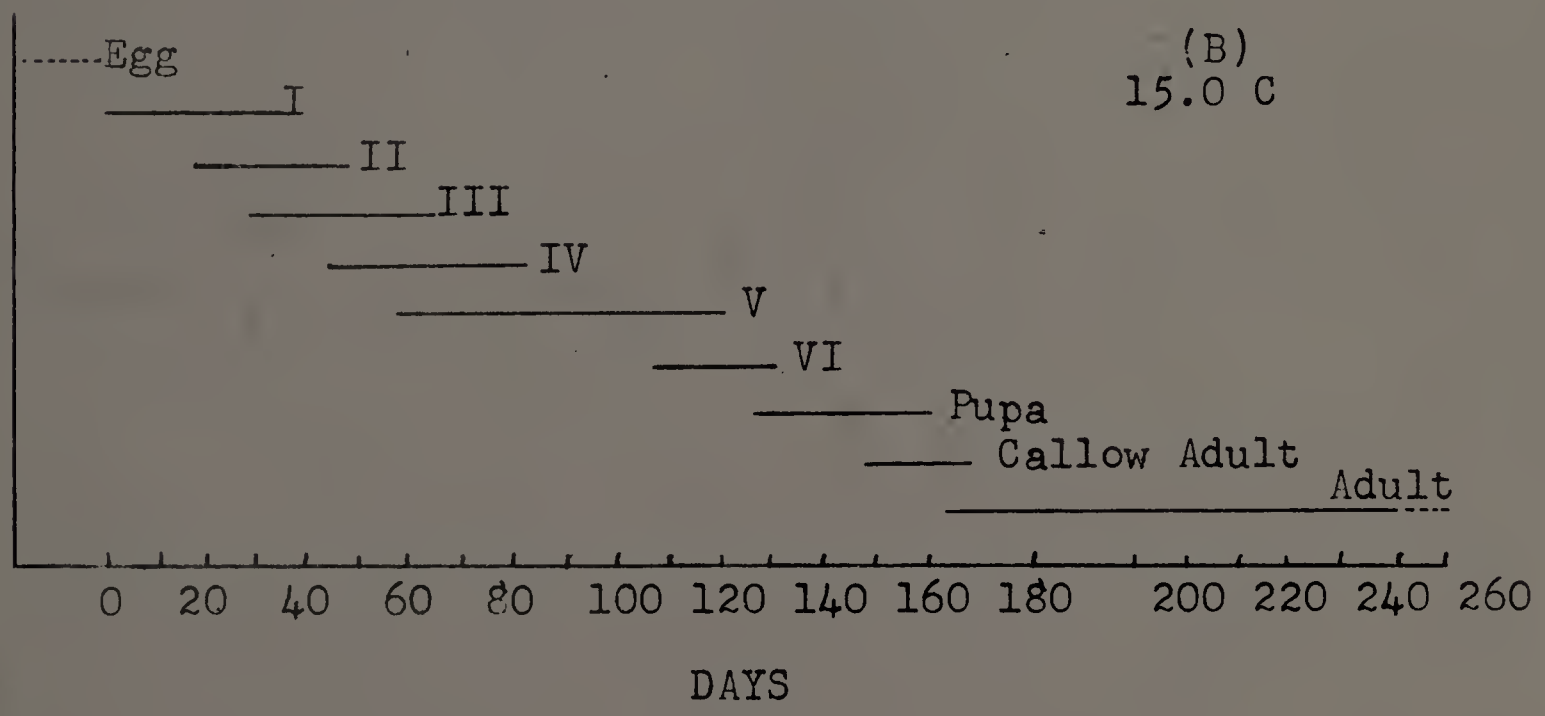


FIGURE 3. Average number of days for development of Dendroctonus valens at different constant temperatures. The developmental time for various instars and stages was based on the first and last insect to moult in the sandwich group. Data taken from Tables 1 and 2.





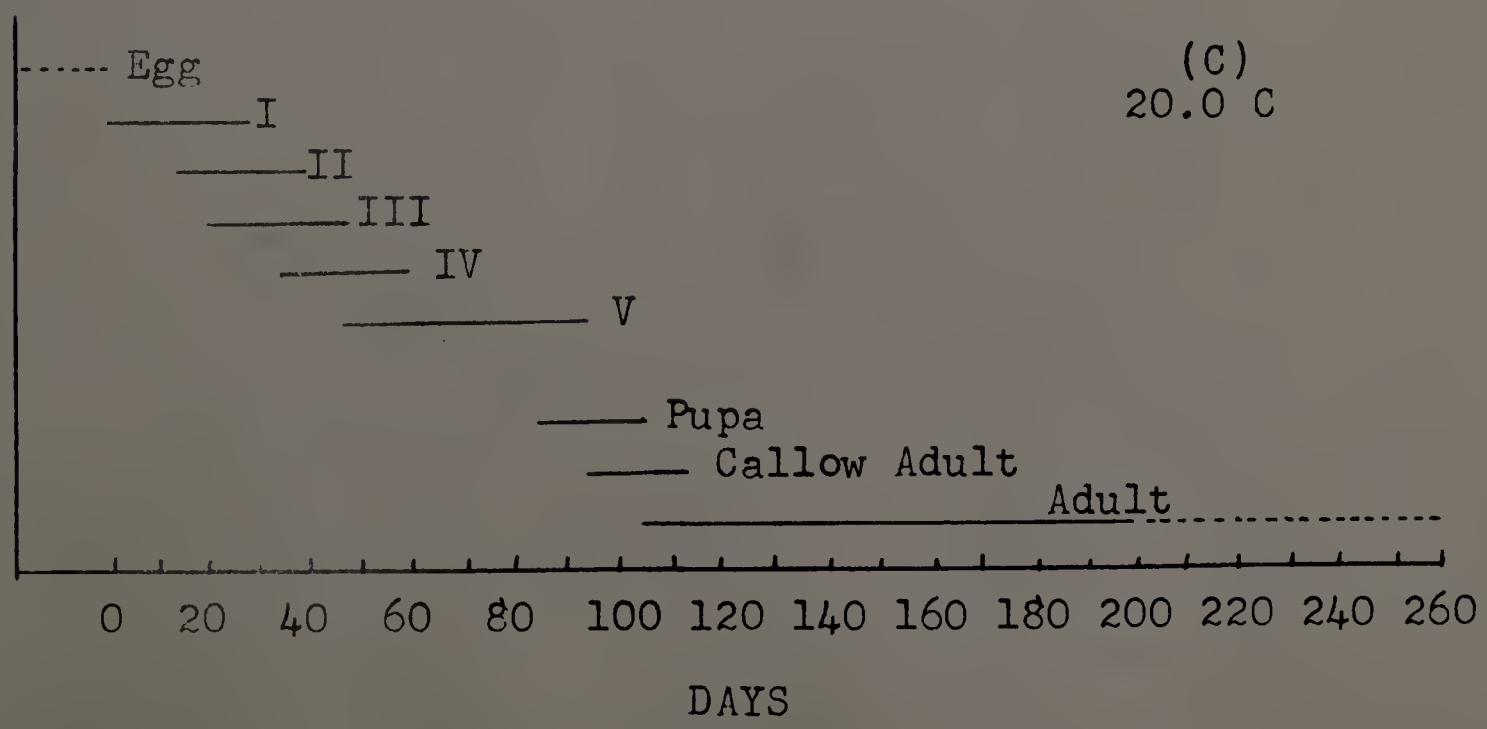
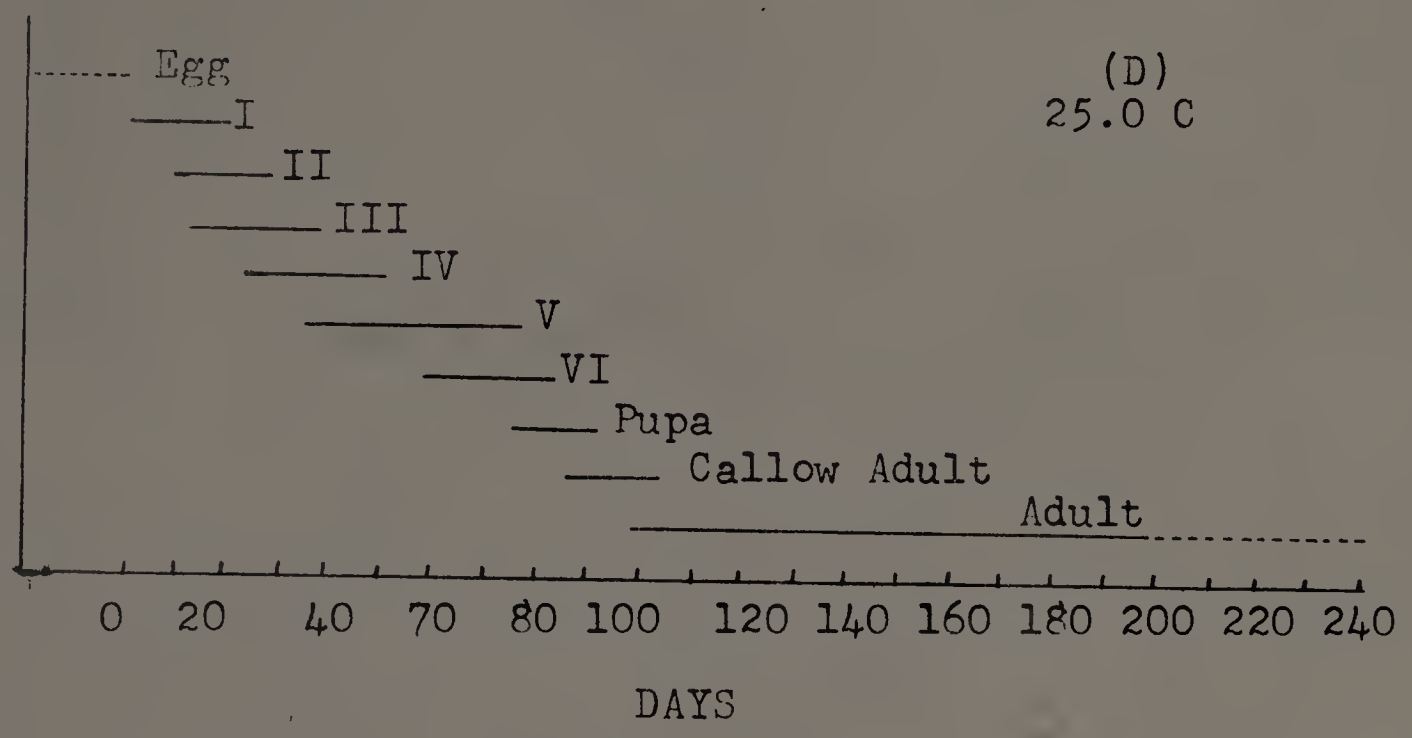


FIGURE 3--Continued



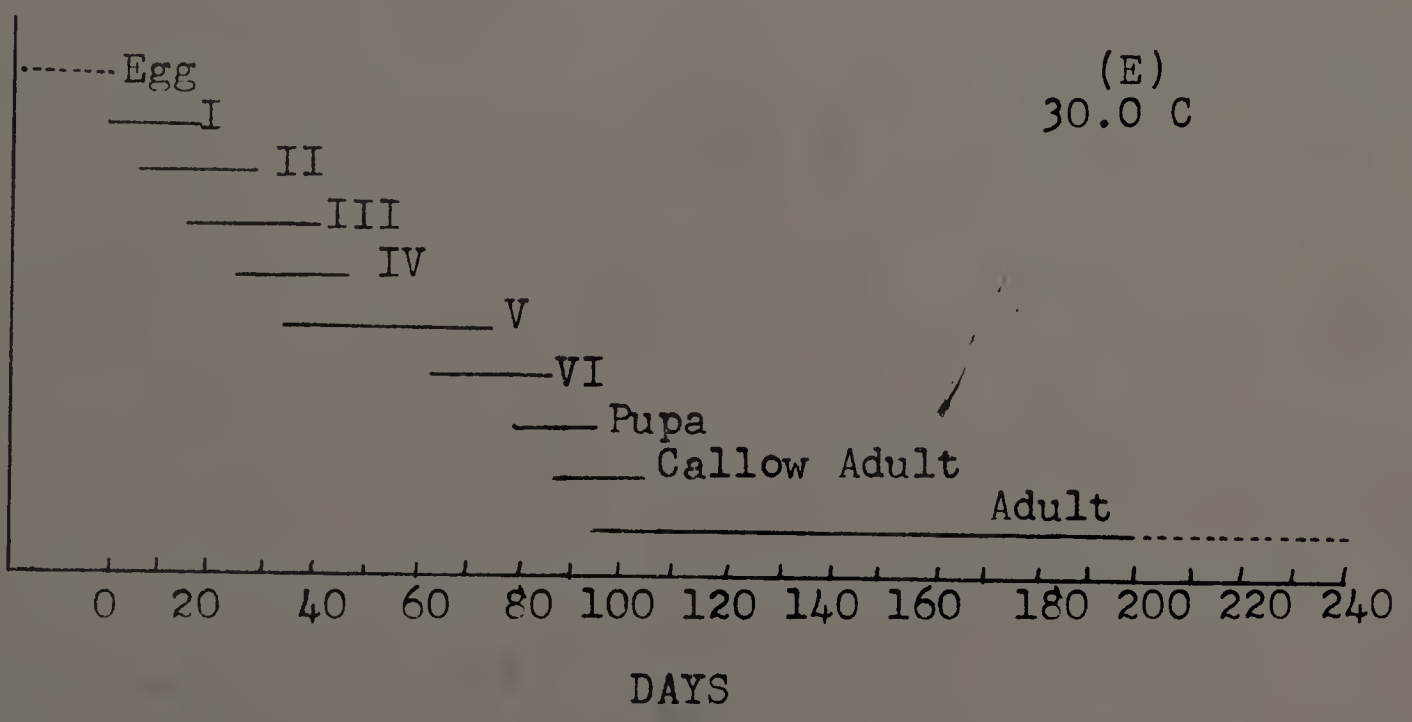


FIGURE 4. Environmental temperatures inside open galleries of Dendroctonus valens at ground level during clear weather on January 21-22, 1964 near Puebla, Mexico. Data taken from Appendix 8.

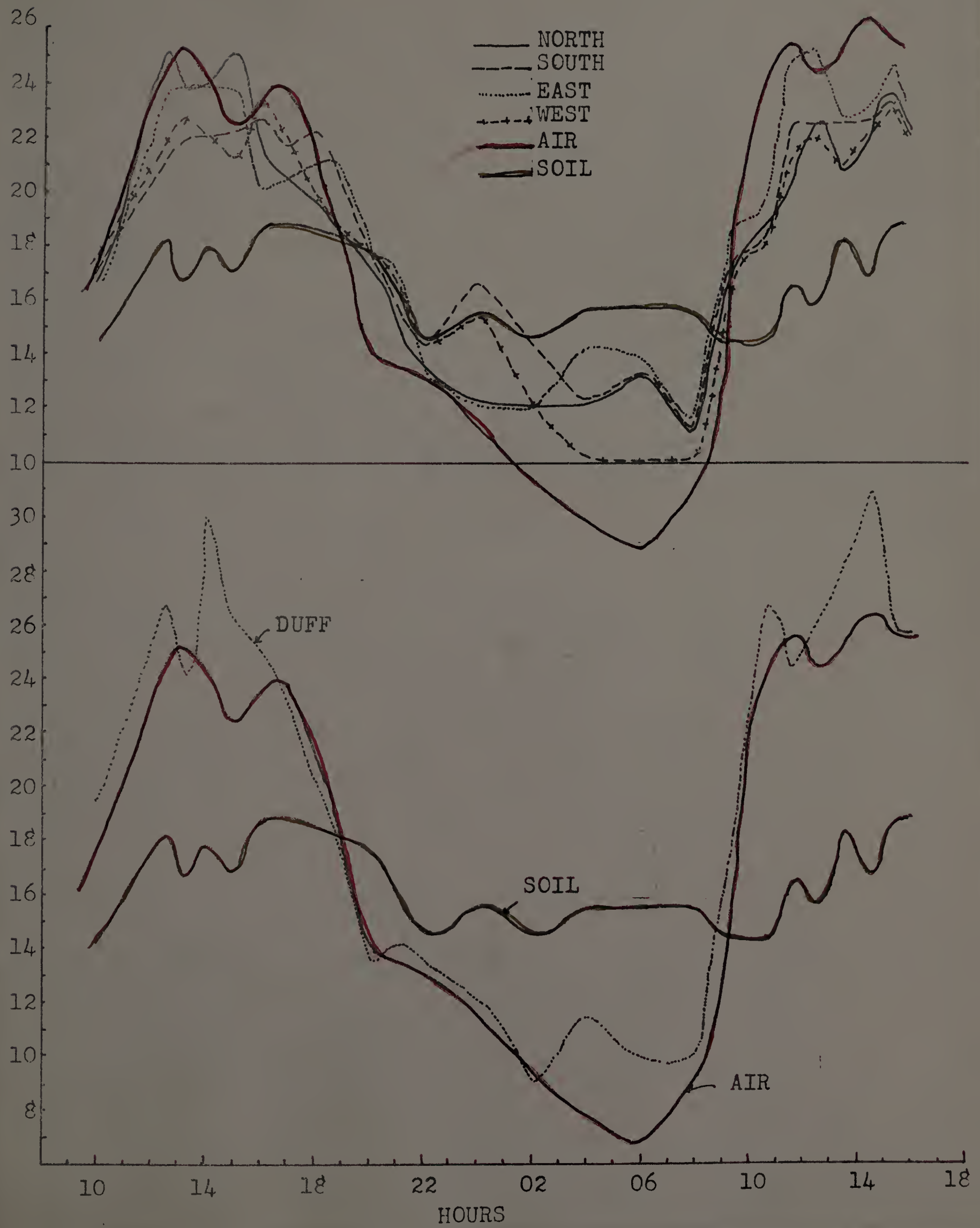


FIGURE 5. Environmental temperatures inside open galleries of Dendroctonus valens at ground level during weather on May 14-15, 1964 near Puebla, Mexico. Data taken from Appendix 9.

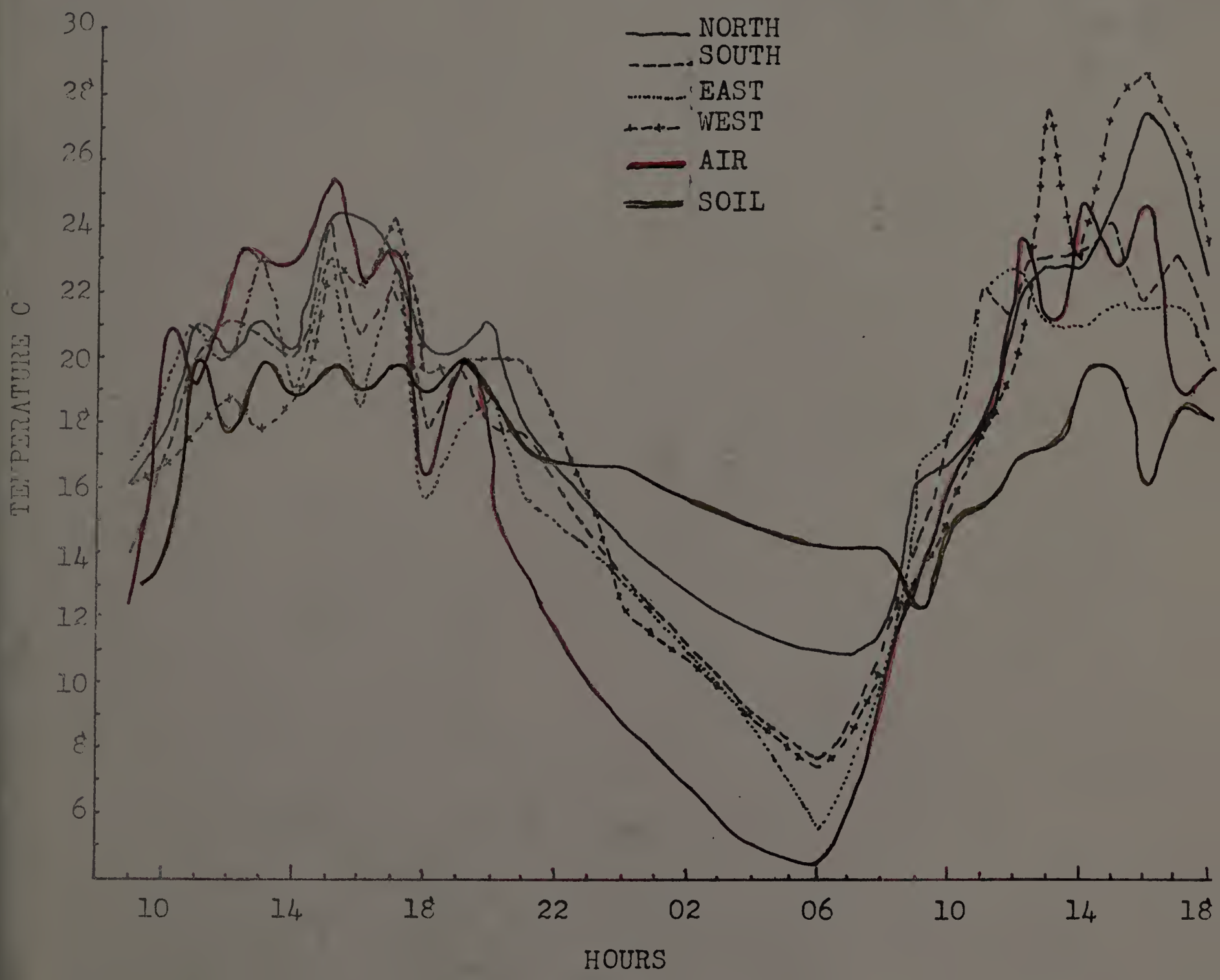


FIGURE 6. Environmental temperatures of Dendroctonus valens during clear weather on May 14-15, 1964 near Puebla, Mexico. Data taken from Appendix 9.

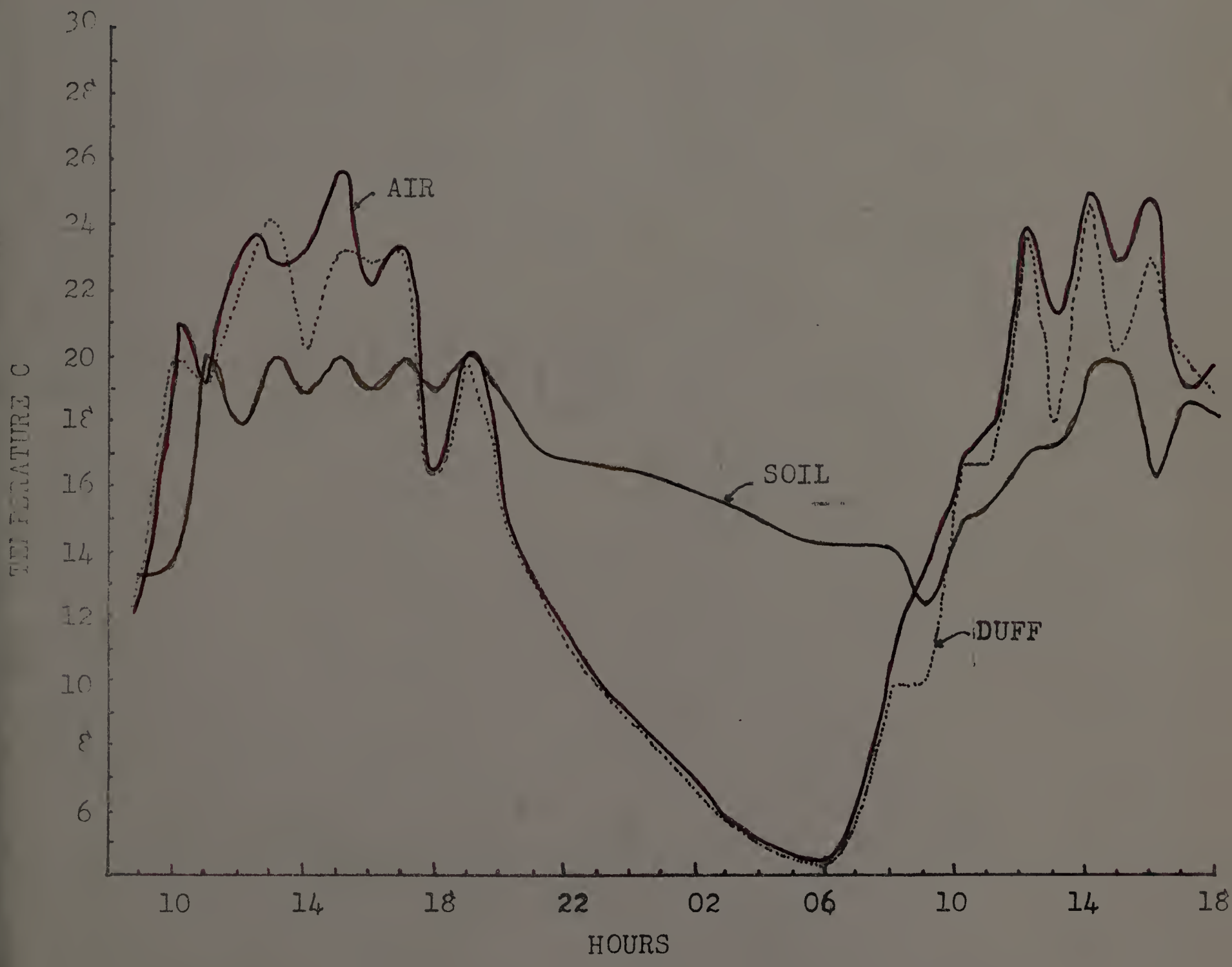


FIGURE 7. Different development stages of D. valens. egg, I, II, III, IV, V, VI larval instars, prepupa, callow adult and three adults. Pupal stage is missing. Scale is in cm.

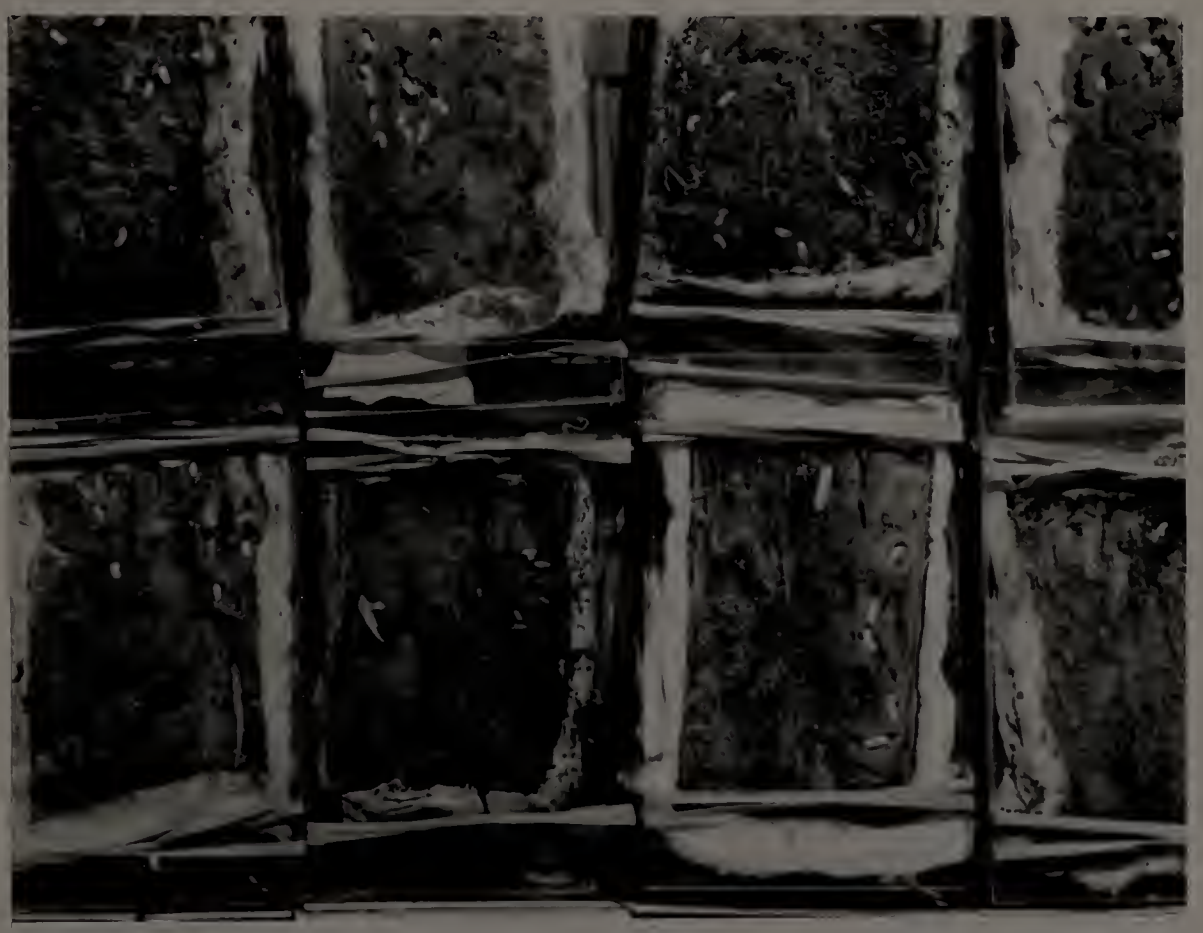


FIGURE 8. Sandwiches used for rearing D. valens in the laboratory.

FIGURE 9. Adult gallery of D. valens leading into roots. Eggs are located at the tip of the scalpal.

FIGURE 10. Field temperature recordings in the natural environment of D. valens. Hygrothermograph and potentiometer are shown.

FIGURE 11. Environmental temperatures inside open galleries of Dendroctonus frontalis one meter above the ground level during clear weather on January 21-22, 1964 near Puebla, Mexico. Data taken from Appendix 10.

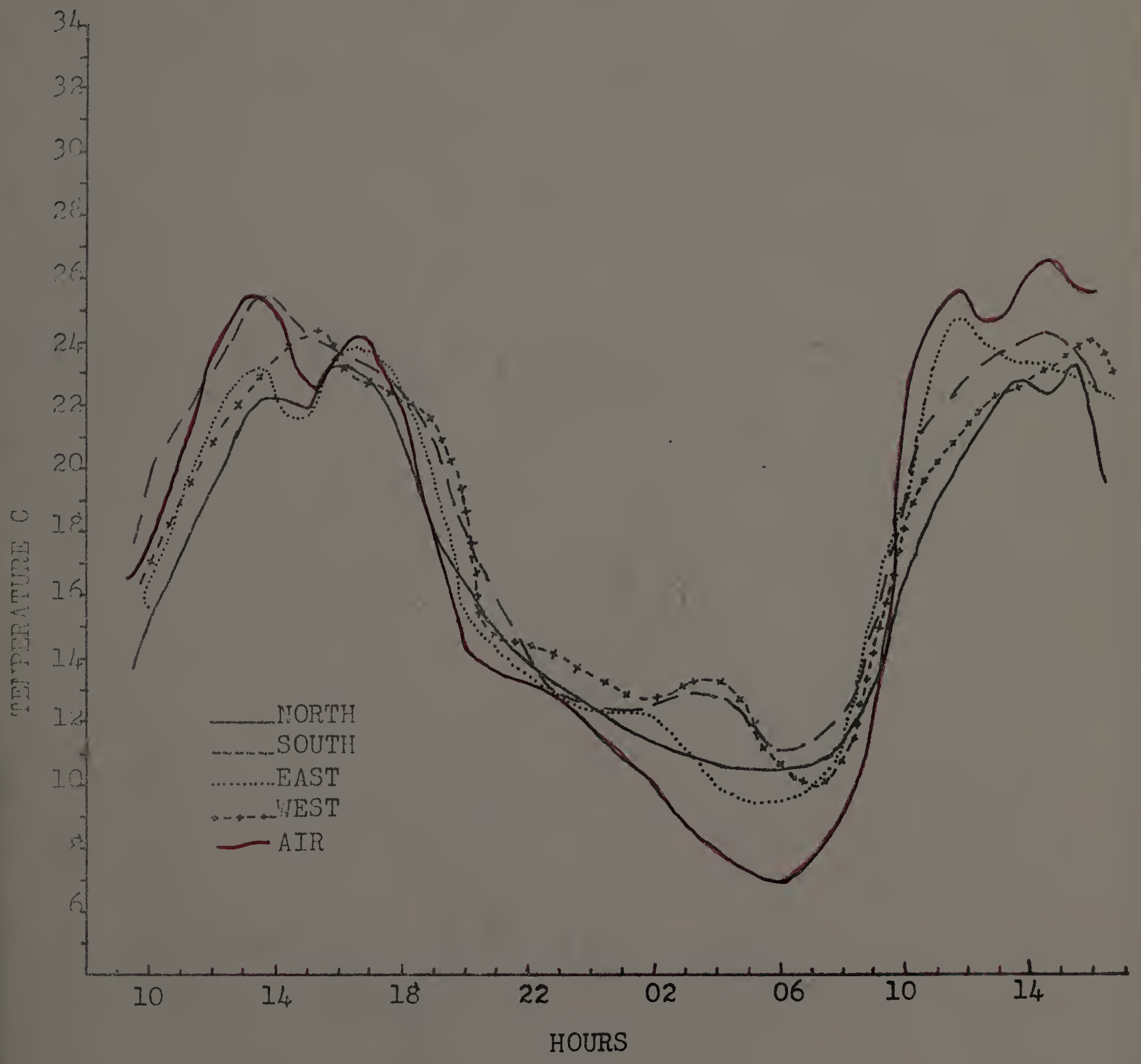


FIGURE 12. Environmental temperatures inside sealed galleries of Dendroctonus frontalis one meter above the ground level during clear weather on January 23, 1964 near Puebla, Mexico. Data taken from Appendix 11.

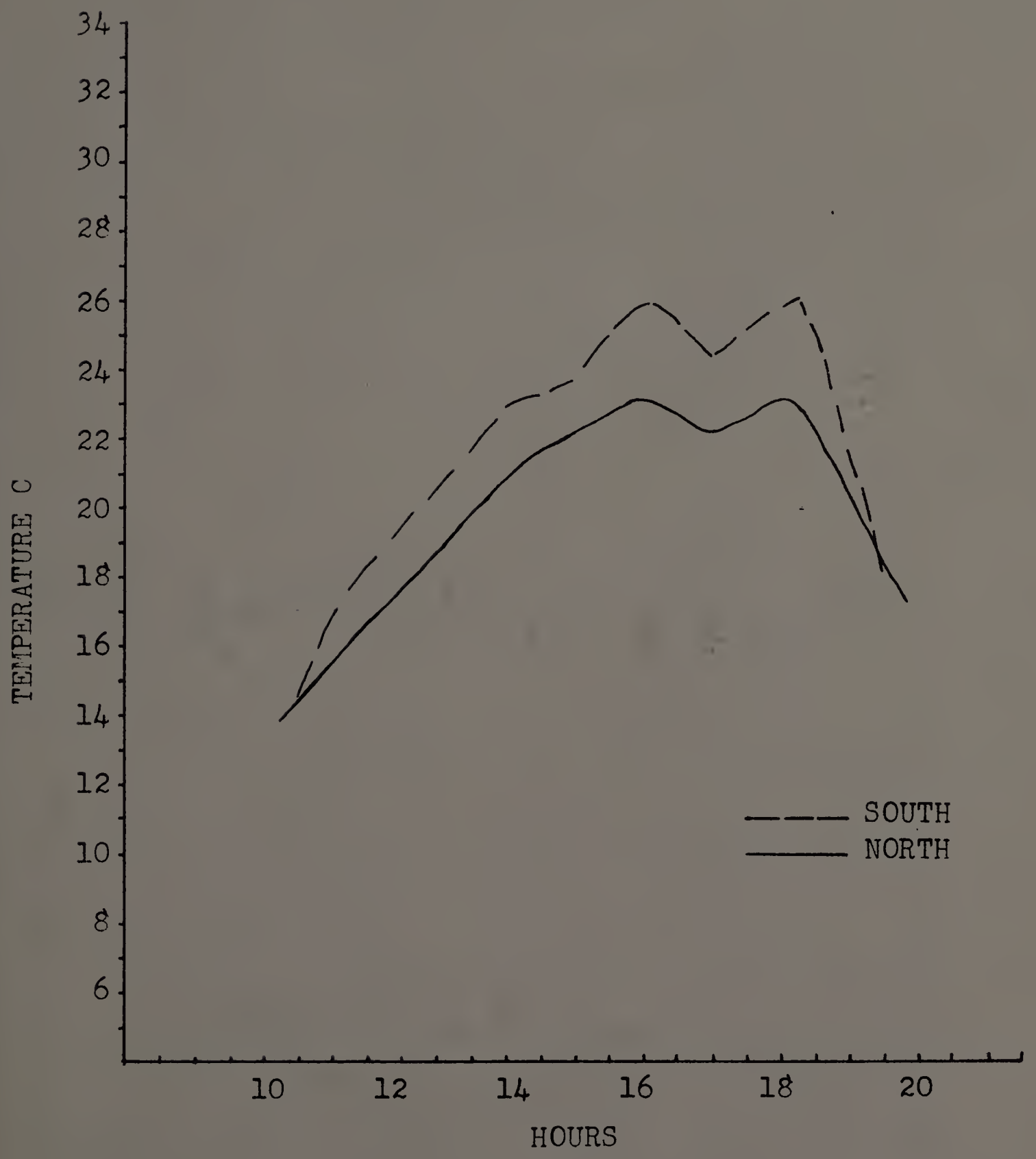


FIGURE 13. Environmental temperatures inside open galleries of Dendroctonus frontalis one meter above the ground level during clear weather on May 14-15, 1964 near Puebla, Mexico. Data taken from Appendix 12.

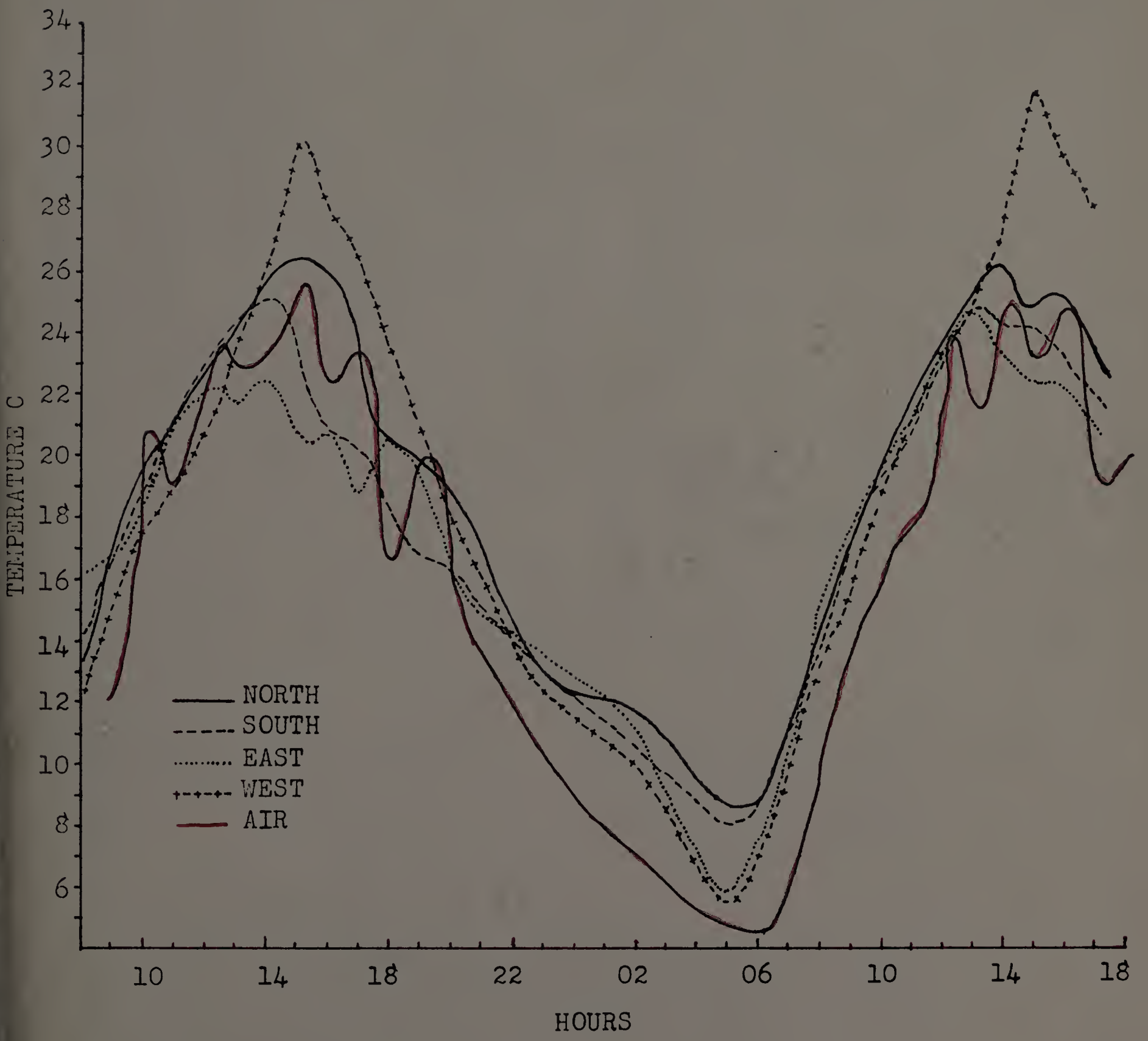


FIGURE 14. The number of days for development of Dendroctonus frontalis at 15 and 26 C. The graph represents the minimum developmental time for the first insect observed to moult in the log samples. Data taken from Tables 3-6.

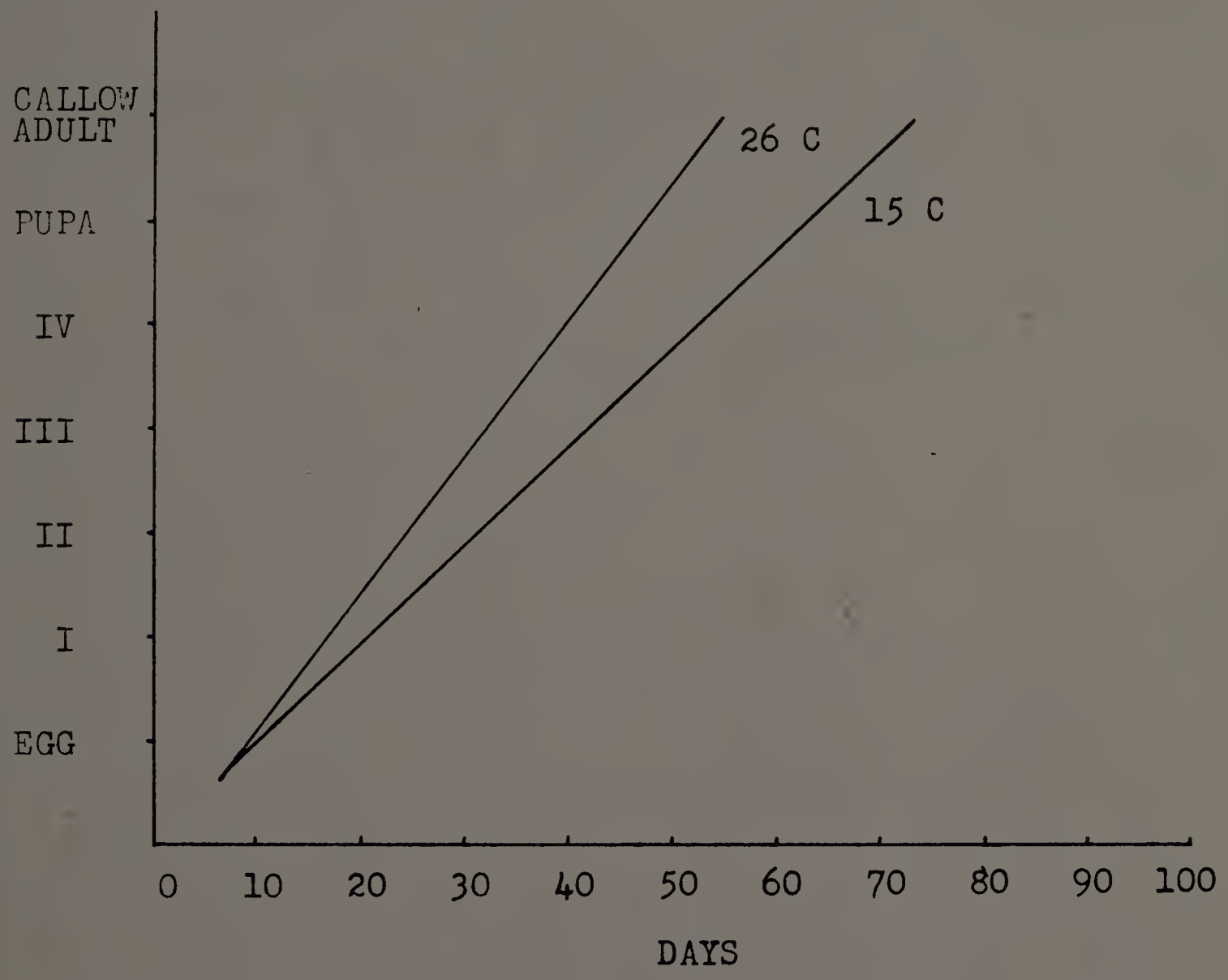
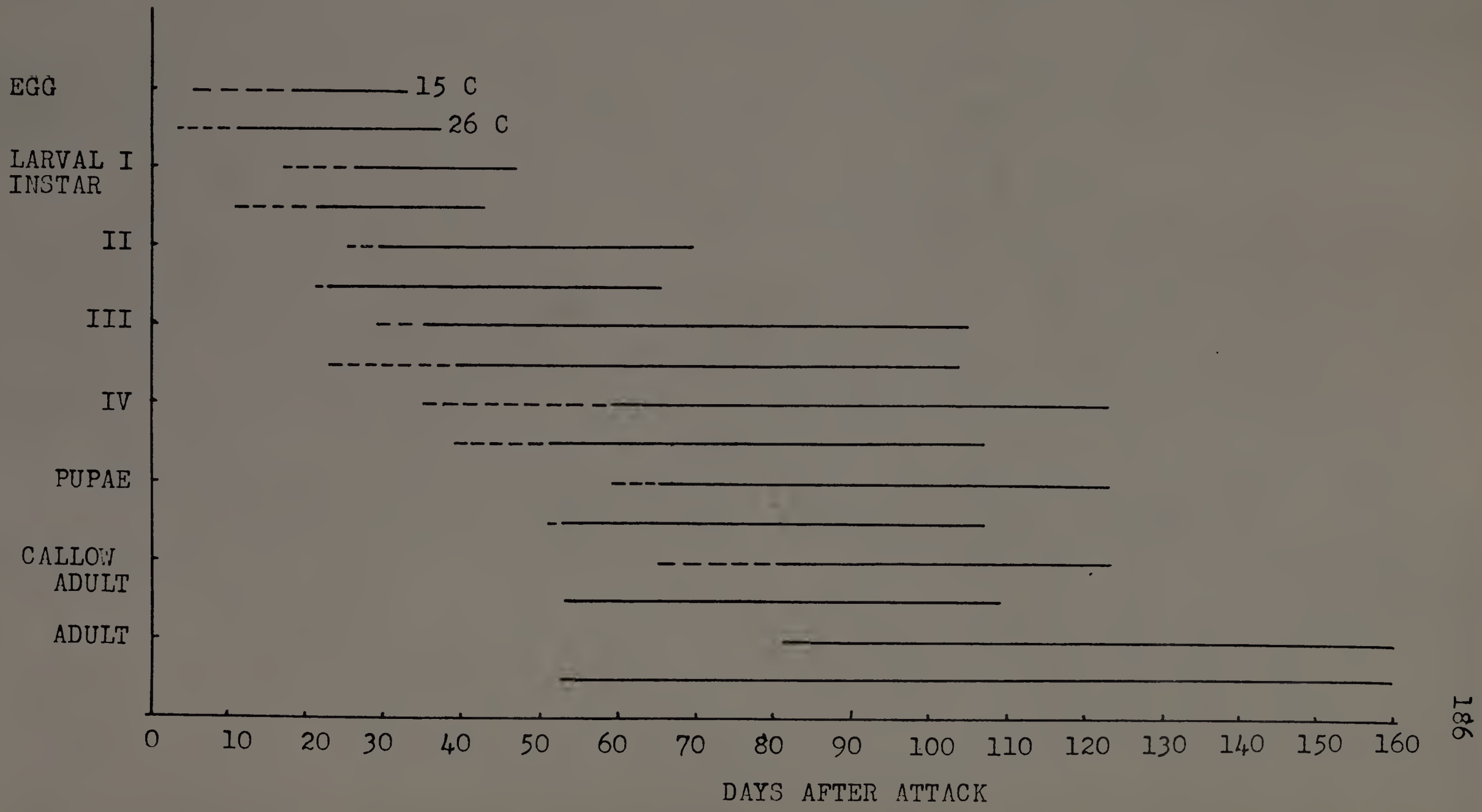


FIGURE 15. Development of Dendroctonus frontalis at 15 and 26 C. The developmental time for the various duration of the instars and stages was based on the first and last insect to moult in the log samples. The dotted lines represents the minimum developmental time for the first insect observed to moult in the samples. Data taken from Tables 3-6.



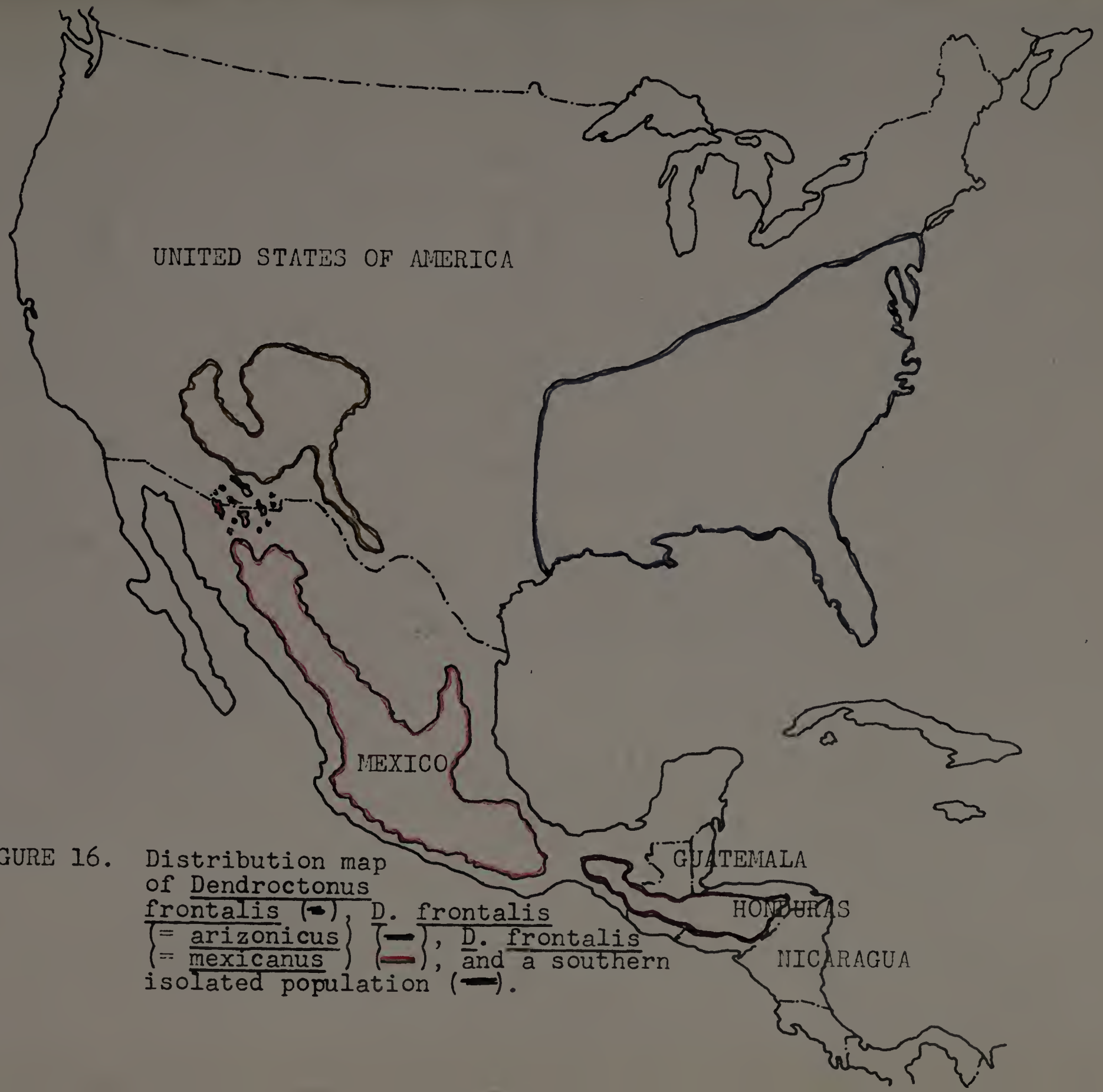


FIGURE 16. Distribution map of Dendroctonus frontalis (▬), D. frontalis (= arizonicus) (▬), D. frontalis (= mexicanus) (▬), and a southern isolated population (▬).

FIGURE 17. External bark surface showing attack by D. frontalis and D. valens At ground line.

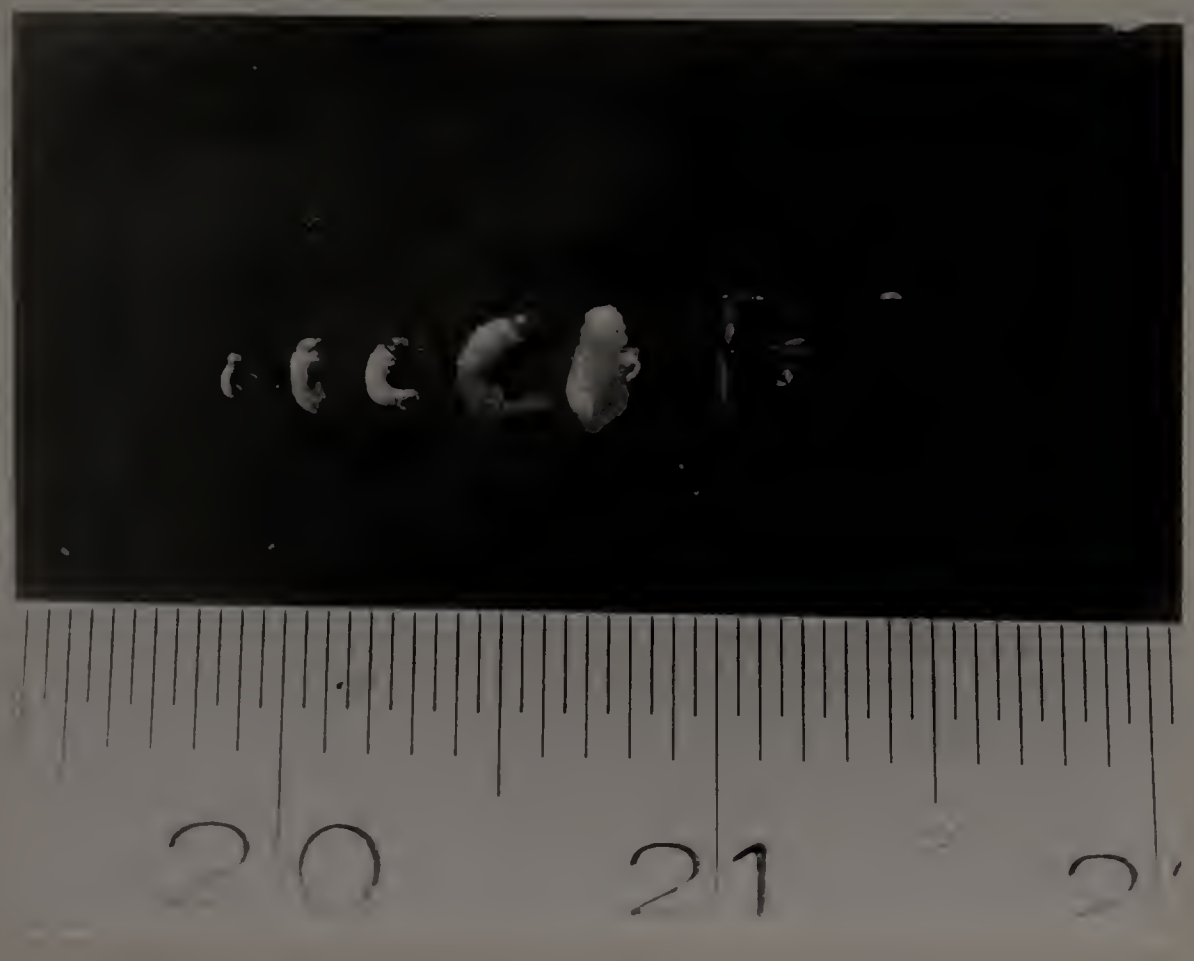


FIGURE 18. Different development stages of D. frontalis; I, II, III, IV, pupa, callow adult, and adult. Scale is in cm.

FIGURE 19. Resin tube caused by D. frontalis upon entry into tree. Entrance hole located on upper edge of tube. Adult killed by resin suffocation.

FIGURE 20. D. frontalis and Ips bonanseai galleries. Note adults, egg niche, and eggs.

FIGURE 21. Adult and larval galleries of D. frontalis 1-2 months after attack. The adult galleries form the cross.

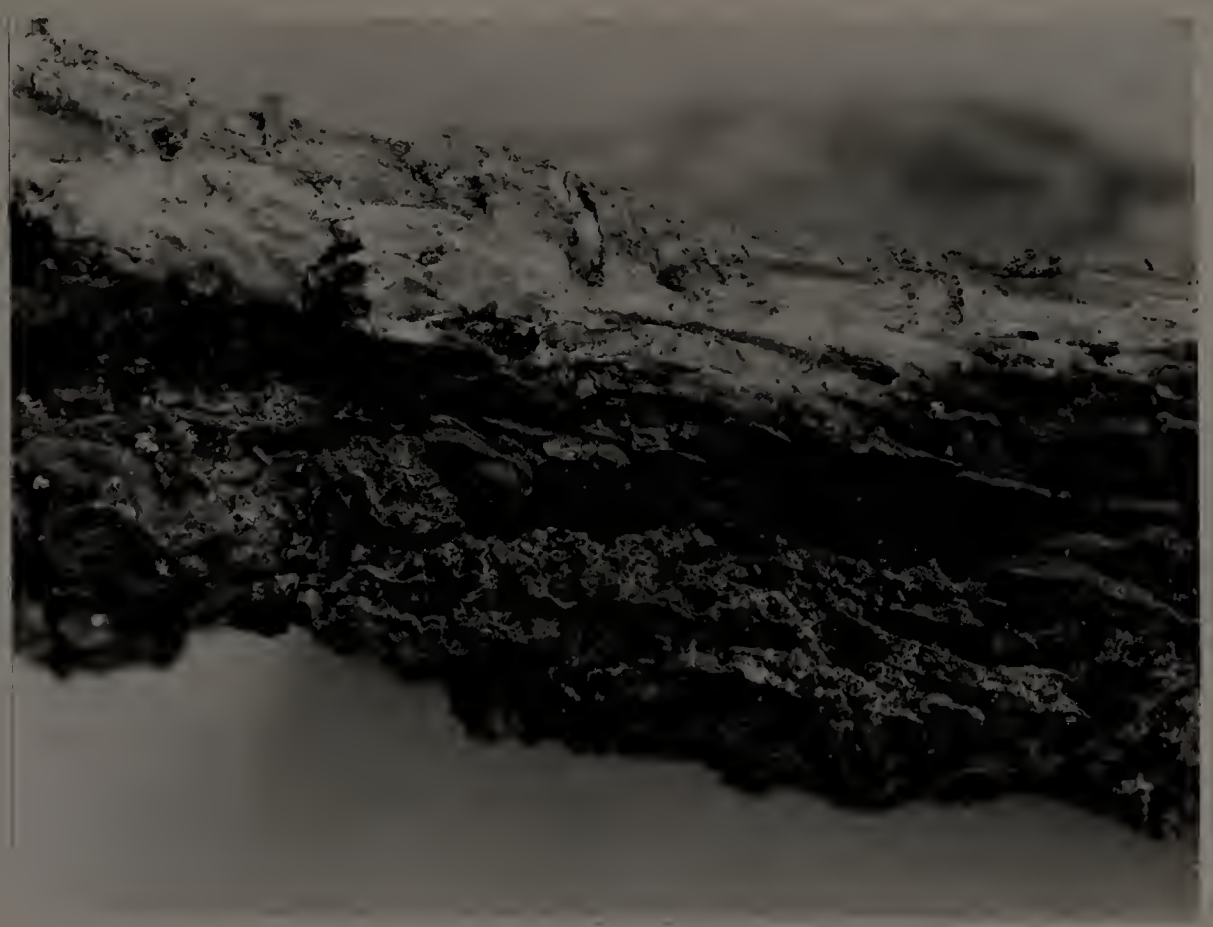


FIGURE 22. Cross section of bark showing larvae and larval galleries of D. frontalis.

FIGURE 23. Cross section of bark showing larval gallery, pupa, and pupal chamber of D. frontalis.

FIGURE 24. D. frontalis galleries etched on xylem surface.

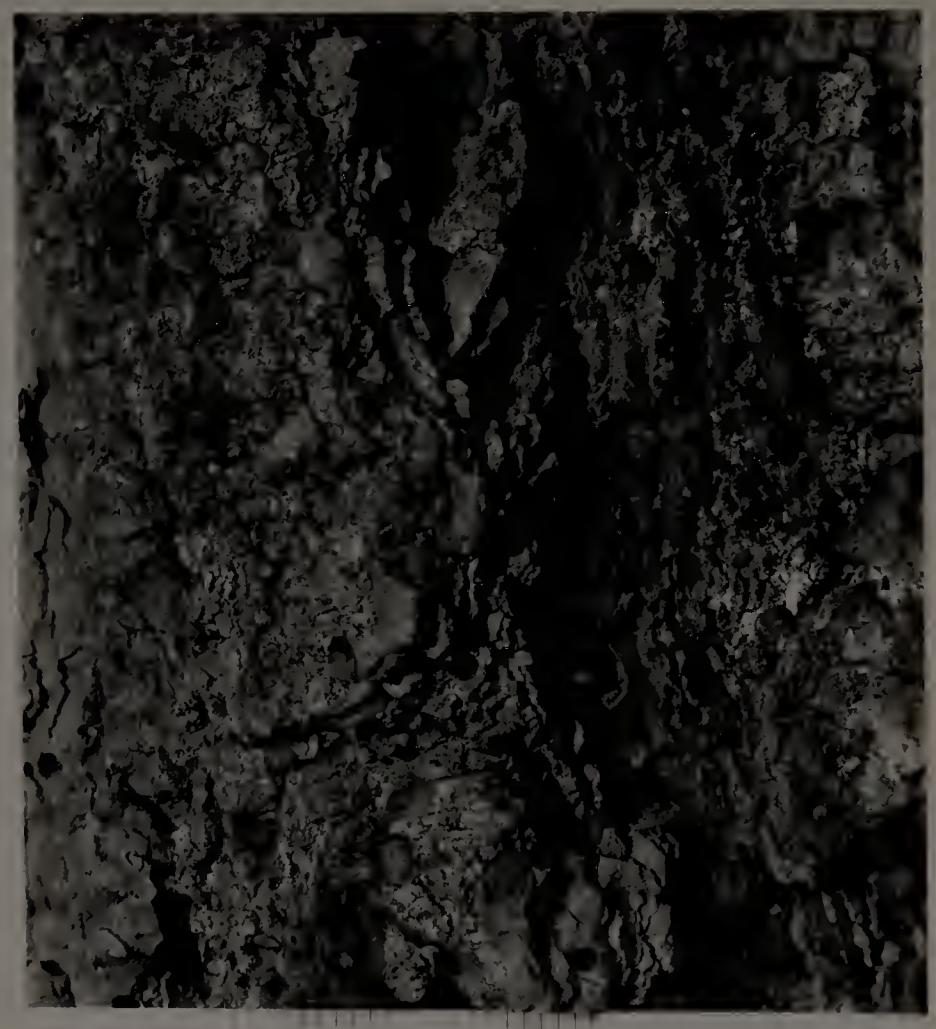


FIGURE 25. Exit holes of emerged adult D. frontalis. Scale is in cm.

FIGURE 26. The average percentage of mortality of Dendroctonus frontalis in logs, in Laboratory Trials 2-6, treated with insecticidal applications. Data plotted on logarithmic probability paper.

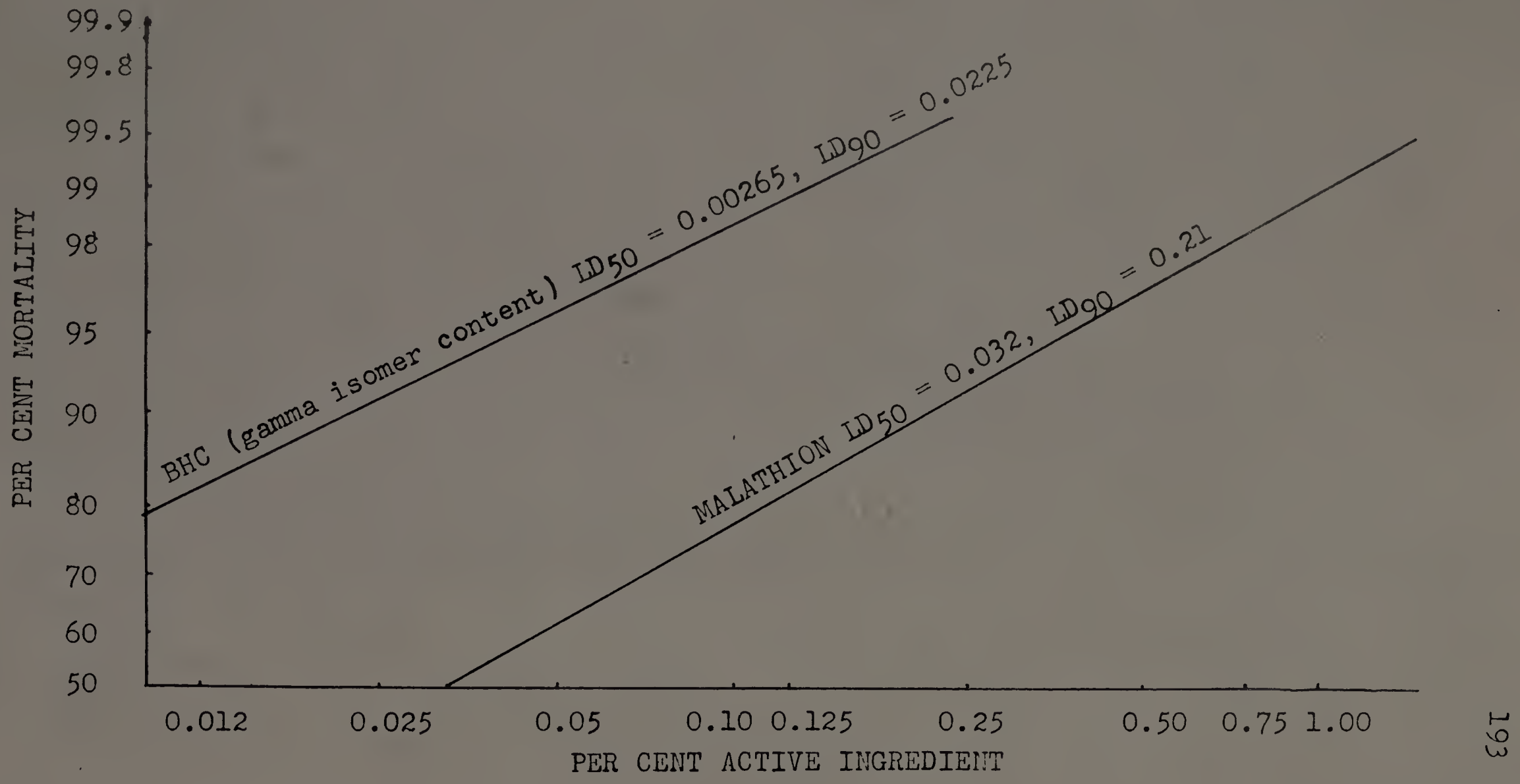


FIGURE 27. The average percentage of mortality of Dendroctonus frontalis in logs, in Laboratory Trials 2-6, treated with insecticidal applications. Data plotted on logarithmic probability paper.

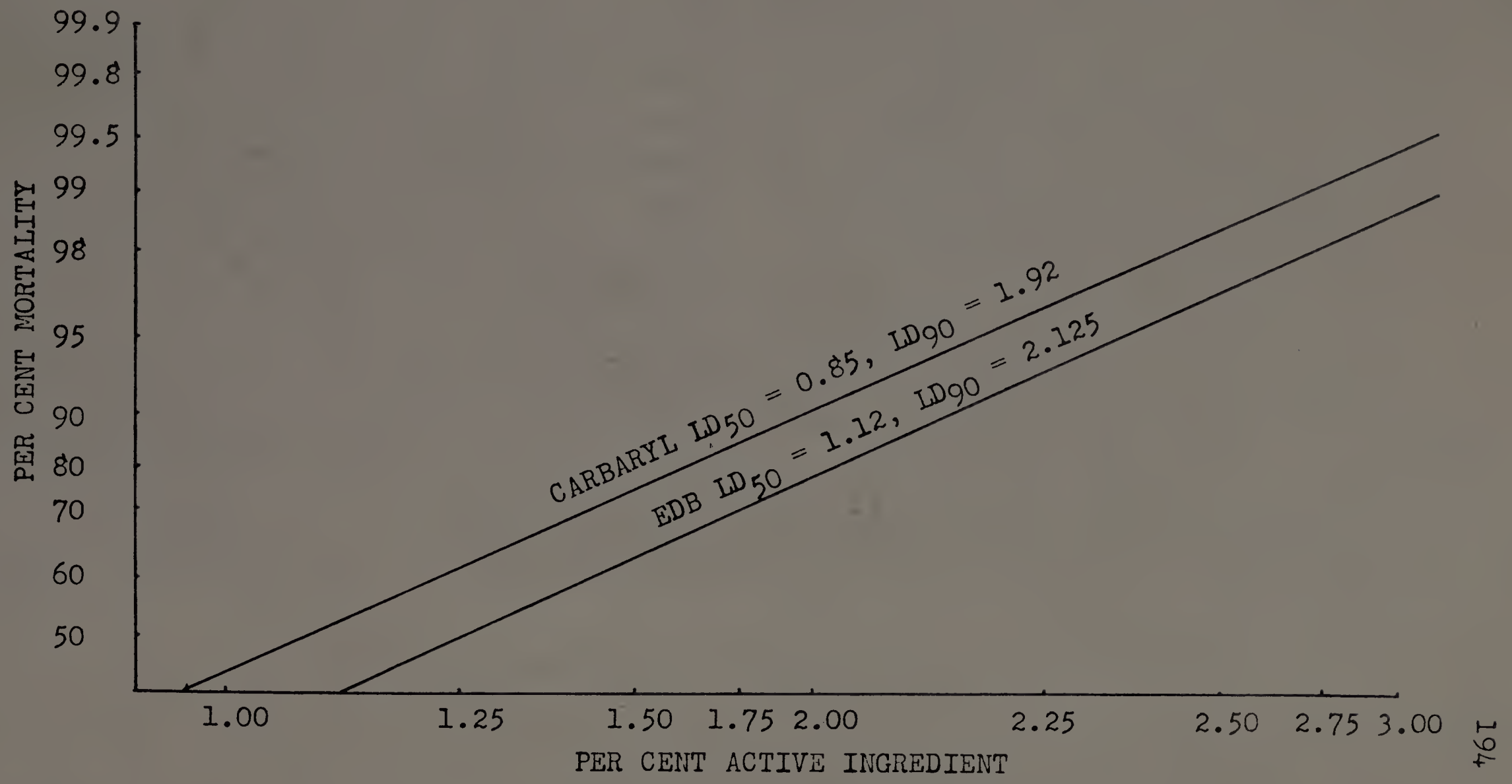


FIGURE 28. The average percentage of mortality of Dendroctonus frontalis from topical application of insecticides. Data plotted on logarithmic probability paper.

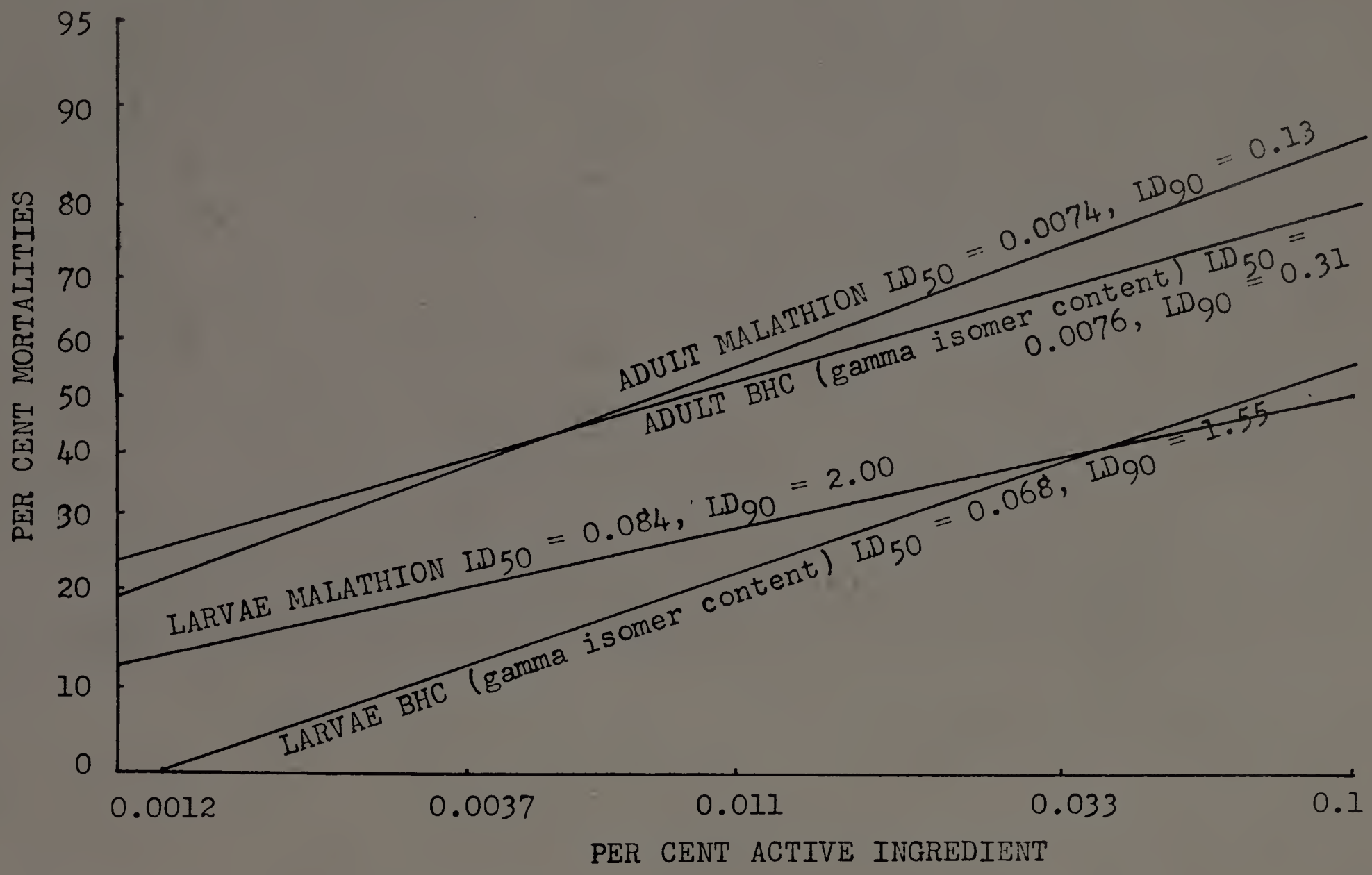


FIGURE 29. The average percentage of mortality of Dendroctonus frontalis in trees treated in the field with insecticides with diesel oil as plotted on logarithmic probability paper.

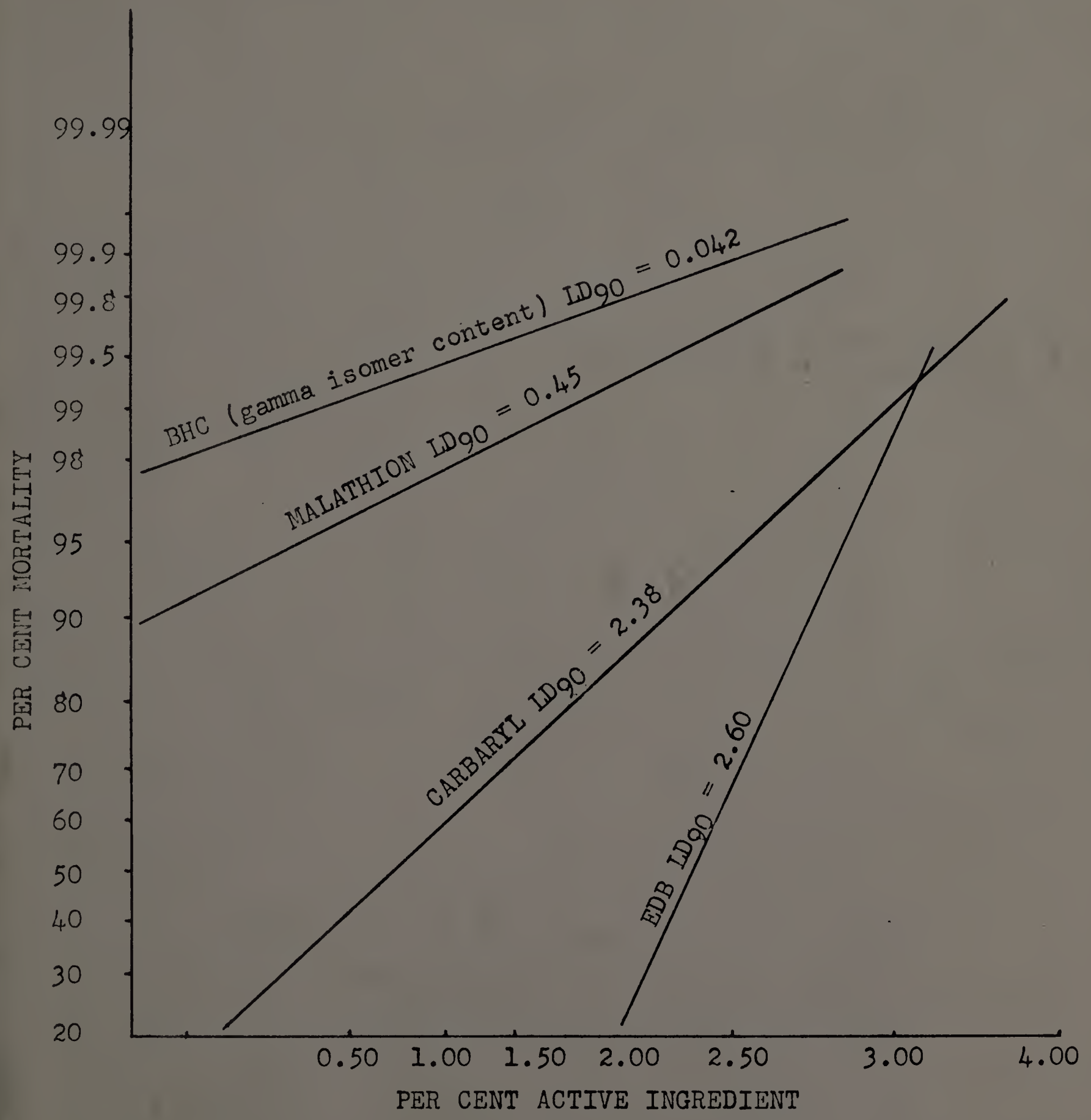


FIGURE 30. The percentage of mortality of Dendroctonus frontalis in logs in the Laboratory Trial 1 treated with insecticides diluted in water alone.

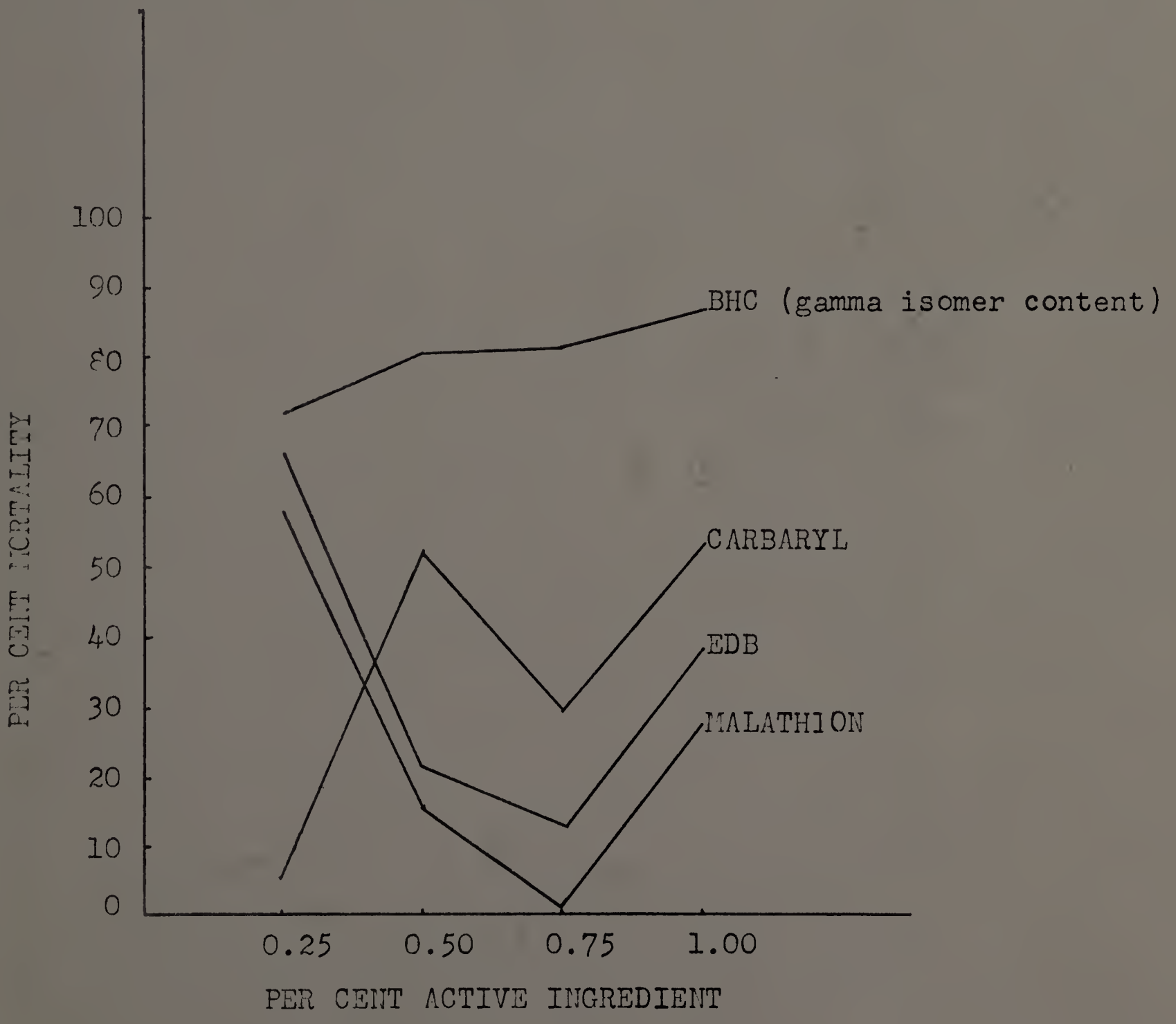


FIGURE 31. Diagram of the 200 liter steel barrel used to house three 85 cm logs in the laboratory experiments with Dendroctonus frontalis.

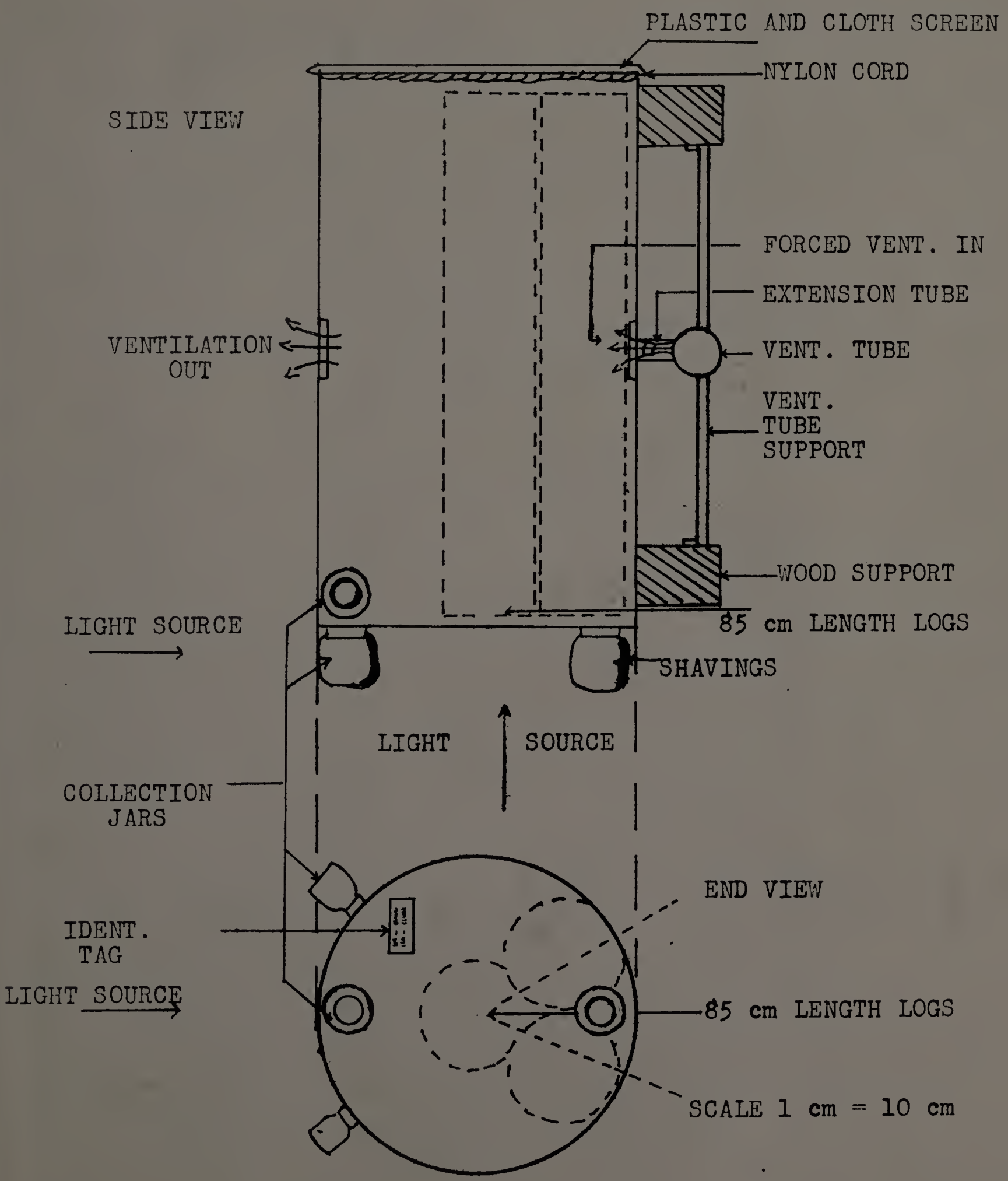


FIGURE 32. Mechanical control of D. frontalis. Trees were felled and limbed. Pue., Mex.

FIGURE 33. Mechanical control of D. frontalis. Logs and stumps barked; bark and stumps were burned. Pue., Mex.

FIGURE 34. Mechanical control of D. frontalis. Peeled bark and ground litter were burned. Pue., Mex.

FIGURE 35. Mechanical control of D. frontalis. Peeled logs were dragged by tractor and decked. Pue., Mex.

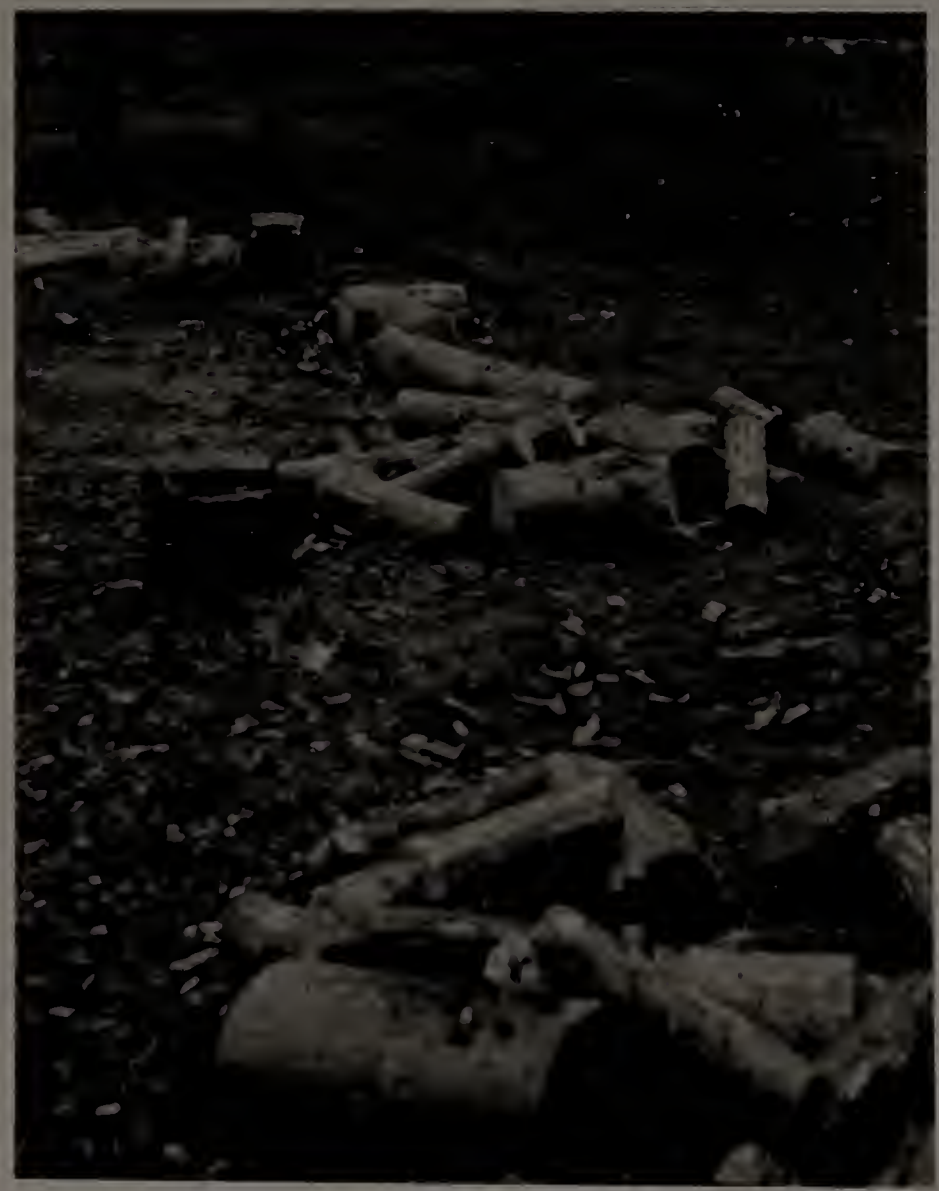


FIGURE 36. Mechanical control of D. frontalis. Peeled logs were bucked into 50 cm length bolts and decked. Pue., Mex.

FIGURE 37. Mechanical control of D. frontalis. Bucked and split bolts were transported to storage pile by donkey. Nicolas Romero, Mex.

FIGURE 38. Mechanical control of D. frontalis. Trees are felled, peeled, bucked, split, and stacked. Bark is being burned and limbs and tops are stacked for firewood. Nicolas Romero, Mex.

FIGURE 39. Equipment used in the chemical control trials against D. frontalis in the field and laboratory.

FIGURE 40. Insecticidal application for laboratory trials. Spray mixture was applied to 85 cm length logs infested with D. frontalis before placement in barrels.

FIGURE 41. Barrels in the laboratory containing treated logs. Note thermostat, collection jars, cloth and plastic cover, wood support, and ventilation system.

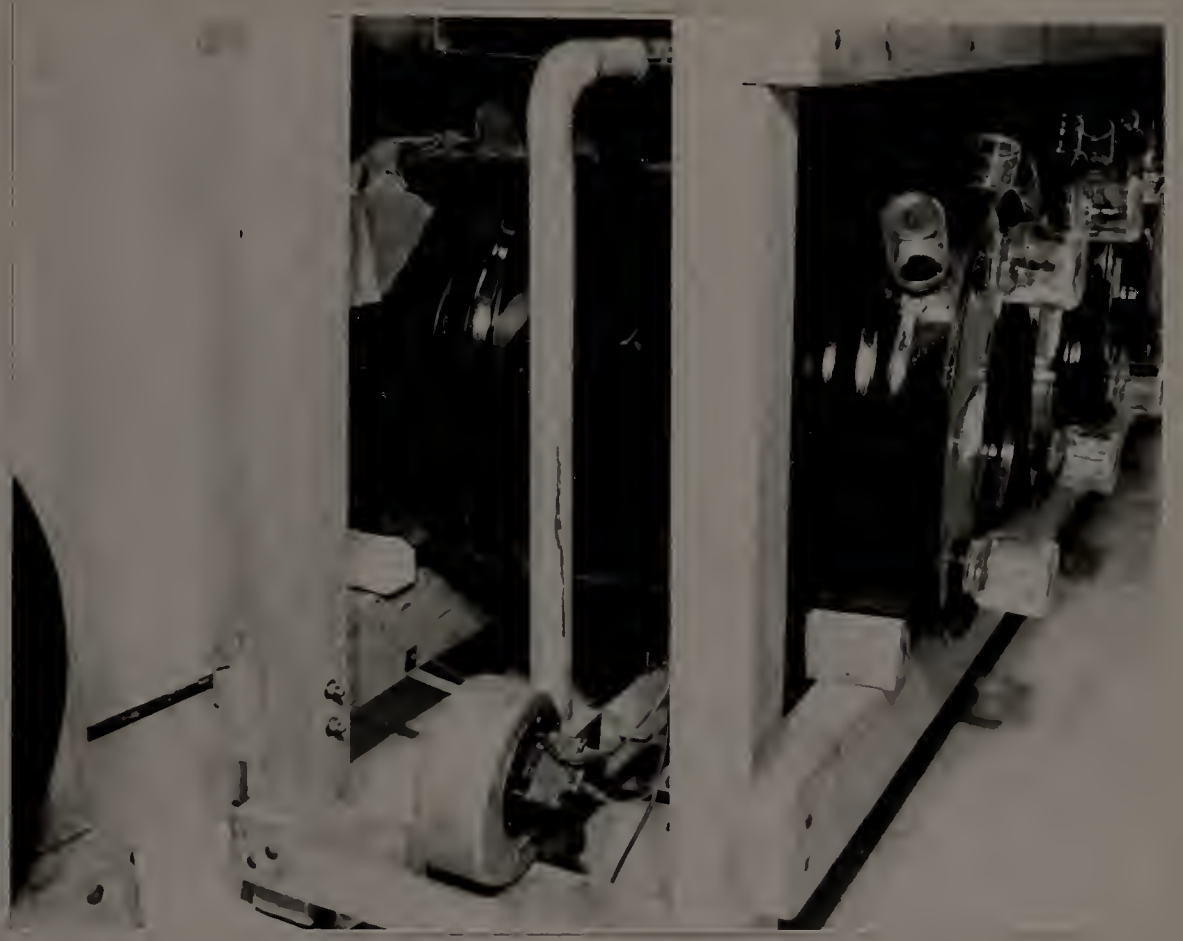


FIGURE 42. Barrels in the laboratory containing treated logs. Note ventilation system and collection jars.

FIGURE 43. Equipment and preparation of spray mixtures for field trials against D. frontalis in the pine forest of the Ex-Hda. Manzanilla, Puebla, Mexico.

FIGURE 44. Spray application on infested Pinus leiophylla trees in field trials against D. frontalis at the Ex-Hda. Manzanilla, Puebla, Mex.

FIGURE 45. The belt sample 10 cm in width for counting exit holes of adults four months after spray application in field trials against D. frontalis at the Ex-Hda. Manzanilla, Puebla, Mex.

FIGURE 46. Bark sample with inner view of galleries four months after spray application in field trials against D. frontalis. Bark sample shown was treated on the right with 1.00% malathion.

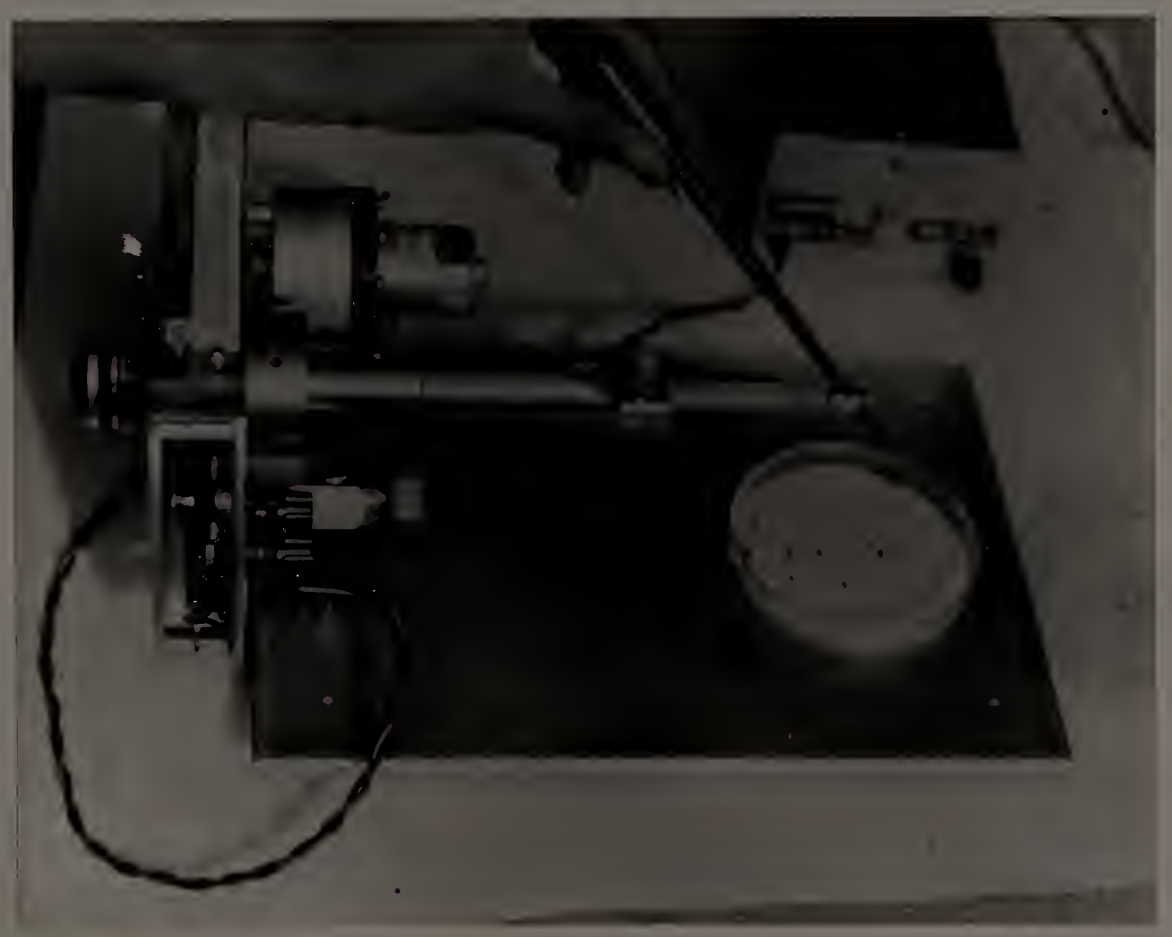


FIGURE 47. Topical applicator. Note the scale, syringe, needle at pointer, and adult beetles in petri dish.

FIGURE 48. Boxes with Acacia plants and Aphis after being exposed for 48 hours to fumigant action in the barrels with sprayed logs.

APPENDIX

APPENDIX 1. Development of Dendroctonus valens at different constant temperatures. The numbers represent the per cent of development per day for the minimum developmental time for the first insect observed in the sandwiches to moult to the next instar or stage. Data taken from Appendix 3-7.

Instar & Stage	Temperature C 8.5	15.0	20.0	25.0	30.0
I	3.7	5.3	7.6	10.8	14.3
II	3.7	8.9	16.4	22.7	14.1
III	9.1	6.8	7.4	10.0	11.0
IV	2.8	7.5	7.4	8.8	9.6
V	3.1	2.0	2.7	4.0	3.6
VI	---[a]	5.6	----[b]	5.2	5.3
Pupae	---	4.7	10.0	8.9	12.3
Callow Adult	---	6.5	9.1	7.0	11.0

[a]Experiment terminated before development was completed.

[b]No data.

APPENDIX 2. Development of Dendroctonus valens at different constant temperatures. The numbers represent the per cent of development per day for the duration of any instar or stage. Data taken from Appendix 3-7.

Instar & Stage	Temperature C 8.5	15.0	20.0	25.0	30.0
I	1.6	2.8	3.7	5.0	5.3
II	1.9	3.5	3.8	5.1	5.2
III	1.3	2.9	3.8	4.3	4.1
IV	1.7	2.6	4.1	4.0	5.2
V	1.6	1.6	2.2	2.4	2.6
VI	---[a]	4.8	---[b]	4.2	4.8
Pupae	---	3.2	5.2	6.2	7.0
Callow Adult	---	5.3	5.6	6.2	6.3

[a]Experiment terminated before development was completed.

[b]No data.

APPENDIX 3. Development of Dendroctonus valens at 8.5 C. The numbers represent the minimum developmental time (Min.) for the first insect observed in the sandwiches to moult to the next instar or stage, and the duration (Dur.) of any instar or stage.

		Sandwich No. 25	30	31	48	64	Mean
		No. Insects at Start 38	21	47	50	16	
I	Min.	27					27.0
	Dur.	64					64.0
II	Min.	38			16		27.0
	Dur.	65			38[a]		51.5
III	Min.			11			11.0
	Dur.			76			76.0
IV	Min.	15		56			35.5
	Dur.	30		85			57.5
V	Min.	32					32.0
	Dur.	65		58[a]			61.5
VI	Min.	109[a]				120[a]	114.5
	Dur.	109[a]				120[a]	114.5

[a]Experiment terminated before development was completed.

APPENDIX 4. Development of Dendroctonus valens at 15 C. The numbers represent the minimum developmental time (Min.) for the first insect observed in the sandwiches to moult to the next instar or stage, and the duration (Dur.) of any instar or stage.

		Sandwich No.													
		23	24	25	25a	25b	25c	25d	26	50	51	65	73	74	Mean
		No. Insects at Start													
		58	51	60	7	25	24	35	14	51	30	30	25	25	
I	Min.										15	21	19	19	18.2
	Dur.										35	30	40	38	35.3
II	Min.	9	2		22					11	6	13	19	8	11.2
	Dur.	28	34		25					33	13	30	30	38	28.7
III	Min.	12	23		8			9		11	2	18		36	14.7
	Dur.	31	54	31	14			29		43	27	38		41	34.2
IV	Min.	10	6					17		13		22			13.3
	Dur.	21	53					29		46		44			38.3
V	Min.	55	76			42	61	50	16	57					51.0
	Dur.	97	96			53	104	94	21	68		27			70.0
VI	Min.								18						18.0
	Dur.								21						21.0
Pupae	Min.	26	21			28	22	20	20	15					21.5
	Dur.	43	27			37	39	26	22	25					31.2
Callow Adult	Min.	13				22	16	20	20	3					15.4
	Dur.	19				22	18	20	20	11					18.2

APPENDIX 5. Development of Dendroctonus valens at 20 C. The numbers represent the minimum developmental time (Min.) for the first insect observed in the sandwiches to moult to the next instar or stage, and the duration (Dur.) of any instar or stage.

		Sandwich No.									
		45	46	49	59	68*	71	78*	79	80	Mean
		No. Insects at Start									
		56	23	24	34	58*	13	25	60	48*	
I	Min.			5				18*	12	18*	13.1
	Dur.			14				25	40	31	27.2
II	Min.		10	12				1	6	2	6.1
	Dur.		25	23				30	32	21	26.1
III	Min.	5	7	6	8*			39	21	11	13.6
	Dur.	23	21	16	28*				40	31	26.3
IV	Min.	14	14	10	14	13	9		17	19	13.6
	Dur.	25	27	23	28*	29	13				24.1
V	Min.	33	48*	41	27	38*	34				36.5
	Dur.	38*	56	48*	42	44	50				46.2
VI	Min.										
	Dur.										
Pupae	Min.	13			14		4				10.1
	Dur.	23			29		6				19.1
Callow Adult	Min.	14			8						11.0
	Dur.	14			22						18.0

APPENDIX 6. Development of Dendroctonus valens at 25 C. The numbers represent the minimum developmental time (Min.) for the first insect observed in the sandwiches to moult to the next instar or stage, and the duration (Dur.) of any instar or stage.

		Sandwich No. 11	12	14a	14b	14c	52	55	57	69	72	81	Mean
		No. Insects at Start 25	25	16	25	25	15	28	25	17	25	25	
I	Min.	5	5								11	18	9.3
	Dur.	15	11								31	24	20.1
II	Min.	4	6				6				7	1	4.4
	Dur.	20	14	13			15				26	31	19.5
III	Min.	7	10				2	10	11	1	20	19	10.0
	Dur.	18	15				26	20	17	14	36	42	23.4
IV	Min.	13	6				31	3	7			9	11.3
	Dur.	26	13				35	16	19			41	25.0
V	Min.		38			6		25	31				25.0
	Dur.		46			22		56	41				41.1
VI	Min.				18	21							19.1
	Dur.				26	23							24.1
Pupae	Min.		10		14	12			10				11.2
	Dur.		12		15	19			20				16.2
Callow Adult	Min.				17	5			12				11.3
	Dur.				17	15			17				16.1

APPENDIX 7. Development of Dendroctonus valens at 30 C. The numbers represent the minimum developmental time (Min.) for the first insect observed in the sandwiches to moult to the next instar or stage, and the duration (Dur.) of any instar or stage.

		Sandwich No.										
		27	28	29	47	53	56	58	62	70	76	Mean
		No. Insects at Start										
		34	21	25	48	20	27	33	20	25	47	
I	Min.					7			4		10	7.0
	Dur.					14			8		35	19.0
II	Min.					3			6	11	9	7.1
	Dur.					12			14	16	36	19.2
III	Min.			7	10	10	6				13	9.1
	Dur.			22	29	22	20				29	24.2
IV	Min.	10		14	9	14	12	12				11.8
	Dur.	22		15	26	22	21	18				20.6
V	Min.	17		17	33			45				28.0
	Dur.	21		28	49			54				38.0
VI	Min.	11	26		19							18.2
	Dur.	13	31		19							21.0
Pupae	Min.	9	7	8				9				8.1
	Dur.	23	14	12				9				14.2
Callow Adult	Min.	7	8	13								9.1
	Dur.	17	14	17								16.0

Appendix 8. Environmental temperatures inside open galleries of Dendroctonus valens at ground level during clear weather on January 21-22, 1964 near Puebla, Mexico.

	Temperature C[a]						
	Subcortical				Air at 1 m[b]		Soil 10 cm Deep
Hour	N.	S.	E.	W.		Duff[c]	
10:00	16.7	17.2	16.7	17.8	17.8	19.4	14.4
12:30	25.0	23.3	23.9	21.7	25.0	26.7	18.3
13:00	23.9	23.9	23.9	22.8	24.4	24.4	16.7
14:00	23.9	22.2	23.9	22.2	25.0	30.0	17.8
15:00	25.0	22.2	23.9	21.1	22.2	26.1	16.7
16:00	21.1	22.8	20.0	23.3	23.3	25.0	18.9
17:00	20.6	21.7	20.6	21.7	23.9	22.8	18.9
18:30	18.9	22.2	21.1	18.9	18.9	19.4	18.3
20:00	17.2	17.8	17.8	17.8	13.3	13.3	17.8
21:00	14.4	15.6	17.2	15.6	13.3	14.4	15.6
22:00	13.3	14.4	13.3	14.4	12.2	13.3	14.4
24:00	12.2	16.7	12.2	15.6	12.2	12.2	15.6
02:00	12.2	14.4	12.2	12.2	8.9	8.9	14.4
04:00	12.2	12.2	14.4	10.0	7.8	11.7	15.6
06:00	13.3	13.3	13.9	10.0	6.7	10.0	15.6
08:00	11.1	11.1	11.1	10.0	8.9	10.0	15.6
09:30	17.8	17.8	18.9	17.8	16.7	18.9	14.4
10:30	18.9	17.8	19.4	18.9	24.4	26.7	14.4
11:30	20.6	22.2	25.0	21.1	25.6	24.4	16.7
12:30	22.8	22.2	25.6	22.2	24.4	26.1	15.6
13:30	20.6	22.2	22.8	21.1	25.0	28.3	18.3
14:30	22.2	22.8	23.3	22.2	26.7	31.1	16.7
15:30	23.9	23.3	25.0	23.9	25.6	25.6	18.9
16:00	22.2	24.4	23.3	22.2	25.6	25.6	18.9

[a]Temperatures for N, S, E, and W were taken by inserting thermocouple junctions about one inch into the open gallery along the cambium.

[b]Air temperatures were taken one meter above the ground level in the shade.

[c]Duff temperatures were taken at the ground level within the pine needles.

APPENDIX 9. Environmental temperatures inside open galleries of Dendroctonus valens at ground level during clear weather on May 14-15, 1964 near Puebla, Mexico.

	Temperature C[a]						
	Subcortical				Air at		Soil 10 cm
Hour	N.	S.	E.	W.	1 m[b]	Duff[c]	Deep
09:00	16.1	13.9	16.7	16.1	12.2	13.9	13.3
10:00	17.8	16.7	18.9	16.7	21.1	20.0	13.3
11:00	21.1	20.0	21.1	17.8	18.9	18.3	20.0
12:00	20.0	21.1	20.0	18.9	23.3	22.2	17.8
13:00	21.1	20.6	23.3	17.8	22.8	24.4	20.0
14:00	20.0	20.0	18.9	18.9	22.8	20.0	18.9
15:00	24.4	24.4	23.3	23.3	25.6	23.3	20.0
16:00	24.4	20.6	18.3	22.2	22.2	22.8	18.9
17:00	22.8	22.2	22.8	24.4	23.3	23.3	20.0
18:00	20.0	17.8	15.6	19.4	16.1	15.6	18.9
19:00	20.0	20.0	17.8	20.0	20.0	20.0	20.0
20:00	21.1	17.8	18.9	20.0	15.6	15.6	18.9
21:00	17.8	17.8	15.6	20.0	13.3	13.3	17.2
24:00	14.4	13.3	13.3	12.2	8.9	8.9	16.7
03:00	12.2	10.0	10.0	10.0	5.6	5.6	15.6
06:00	11.1	7.8	5.6	7.8	4.4	4.4	14.4
08:00	11.7	11.7	11.7	11.1	10.6	10.0	14.4
09:00	16.1	14.4	16.7	13.3	13.3	10.0	12.2
10:00	16.7	17.8	17.8	15.6	16.7	16.7	15.0
11:00	18.3	22.2	22.2	18.3	17.8	16.7	15.6
12:00	21.7	21.1	22.8	20.0	23.9	24.4	17.2
13:00	22.8	23.3	21.1	27.8	21.1	17.8	17.2
14:00	22.8	23.3	21.1	22.8	25.0	25.0	20.0
15:00	25.0	24.4	21.7	27.8	22.8	20.0	20.0
16:00	27.8	21.7	21.7	28.9	25.0	23.3	16.1
17:00	26.1	23.3	21.7	27.2	18.9	20.0	18.9
18:00	22.8	21.1	20.0	23.3	20.0	18.9	18.3

[a]Temperatures for N, S, E, and W were taken by inserting thermocouple junctions about one inch into the open gallery along the cambium.

[b]Air temperatures were taken one meter above the ground level in the shade.

[c]Duff temperatures were taken at the ground level within the pine needles.

APPENDIX 10. Environmental temperatures inside open galleries of Dendroctonus frontalis one meter above the ground level during clear weather on January 21-22, 1964 near Puebla, Mexico.

Hour	Temperature C[a] Subcortical N.	S.	E.	W.	Air at 1 m[b]
10:00	15.6	20.0	16.7	17.8	17.8
12:30	20.0	23.9	22.2	20.0	25.0
13:00	22.2	26.1	23.3	23.3	24.0
14:00	22.2	23.9	21.7	22.2	25.0
15:00	21.1	24.4	22.2	25.0	22.0
16:00	23.9	23.3	23.9	23.3	23.3
17:00	22.8	23.3	23.3	22.8	23.9
18:30	18.9	22.2	21.1	22.2	18.9
20:00	15.6	16.7	15.0	15.6	13.3
21:00	14.4	16.7	14.4	14.4	13.3
22:00	14.4	14.4	13.3	14.4	12.2
24:00	12.2	12.2	12.2	13.3	12.2
02:00	12.2	12.2	12.2	12.2	8.9
04:00	10.0	13.3	10.0	13.3	7.8
06:00	10.5	10.0	9.4	10.0	6.7
08:00	10.5	12.2	11.1	10.0	8.9
09:30	17.2	17.2	18.9	18.9	16.7
10:30	17.2	21.1	19.4	18.9	24.4
11:30	20.5	22.2	25.0	20.5	25.6
12:30	21.1	23.3	23.9	22.2	24.4
13:30	22.8	23.9	23.3	22.2	25.0
14:30	22.2	24.4	23.3	23.3	26.7
15:30	23.3	23.3	22.8	23.3	25.6
16:00	21.1	23.3	22.8	24.4	25.6

[a]Temperature for N, S, E, and W were taken by inserting thermocouple junctions about one inch into the open gallery along the cambium.

[b]Air temperatures were taken one meter above the ground level in the shade.

APPENDIX 11. Environmental temperatures inside sealed galleries of Dendroctonus frontalis one meter above the ground level during clear weather on January 23, 1964 near Puebla, Mexico.

Hour	Temperature C[a] Subcortical N.	S.
10:30	14.4	14.4
11:00	15.6	17.2
11:30	16.7	18.3
12:00	19.4	22.2
12:30	17.8	19.4
13:00	20.0	21.7
13:30	21.1	23.3
14:00	21.7	23.3
14:30	21.7	23.3
15:00	22.8	25.0
15:30	23.3	26.1
16:00	22.8	25.5
16:30	22.2	24.4
17:40	23.3	26.1
18:00	22.2	24.4
19:00	18.3	18.3

[a]Temperature for N and S were taken by inserting thermocouple junctions about one inch into the gallery along the cambium and sealing them in place.

APPENDIX 12. Environmental temperatures inside open galleries of Dendroctonus frontalis one meter above the ground level during clear weather on May 14-15, 1964 near Puebla, Mexico.

Hour	Temperature C[a] Subcortical N.	S.	E.	W.	Air at 1 m[b]
09:00	13.3	13.9	16.1	12.2	12.2
10:00	17.8	14.4	16.7	16.7	21.1
11:00	20.0	20.5	16.7	17.2	18.9
12:00	22.2	21.1	21.1	18.9	23.3
13:00	21.7	23.3	22.2	20.5	22.8
14:00	23.3	22.8	21.1	23.3	22.8
15:00	26.1	25.5	22.8	26.1	25.6
16:00	27.2	21.1	20.0	30.5	22.2
17:00	25.0	22.2	21.1	27.8	23.3
18:00	20.0	17.8	17.8	26.7	16.1
19:00	20.0	21.1	21.1	22.2	20.0
20:00	21.1	15.6	20.1	21.1	15.6
21:00	17.8	17.8	15.6	17.8	13.3
24:00	12.2	13.3	13.3	12.2	8.9
03:00	12.2	10.0	11.1	10.0	5.6
06:00	7.8	7.8	5.5	5.5	4.4
08:00	10.0	11.1	11.1	10.0	10.6
09:00	15.6	13.3	16.7	13.3	13.3
10:00	18.9	18.9	16.7	15.6	16.7
11:00	20.0	18.9	21.1	18.9	17.8
12:00	22.2	20.0	21.1	21.1	23.9
13:00	24.4	23.3	21.1	24.4	21.1
14:00	25.0	25.0	25.0	24.4	25.0
15:00	26.7	23.9	23.3	26.7	22.8
16:00	24.4	24.4	22.2	32.2	25.0
17:00	25.5	22.8	22.2	30.0	18.9
18:00	23.3	22.2	21.1	28.3	20.0

[a]Temperature for N, S, E, and W were taken by inserting thermocouple junctions about one inch into the open gallery along the cambium.

[b]Air temperatures were taken one meter above the ground level in the shade.

APPENDIX 13. The average temperatures at the federal weather station at Puebla, Mexico.

Year	Average Monthly Temperature C. JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEPT.	OCT.	NOV.	DEC.	Total for Year	Average Annual Temp.
1958	12.2	14.6	19.2	21.2	19.0	19.4	18.4	19.1	18.0	18.1	16.2	14.7	210.1	17.5
1959	13.8	18.9	19.3	18.9	17.9	19.1	17.9	18.2	18.4	18.1	15.9	14.4	210.8	17.6
1960	15.4	15.4	18.6	19.7	20.6	20.6	18.5	19.4	17.6	18.8	16.7	14.5	215.8	18.0
1961	----	---[a]	17.6	20.3	20.4	----	17.7	18.4	17.4	16.7	15.8	14.4	-----	17.6
1962	8.1	17.1	14.8	13.8	19.5	16.7	14.7	15.2	15.1	14.2	9.9	10.8	169.9	14.2
1963	15.1	9.7	19.2	15.9	19.5	16.2	14.4	14.8	14.2	16.2	10.0	14.2	179.4	15.0
1964	----	16.8	----	----	18.7	17.1	----	17.9	17.8	----	----	----	-----	17.7
	Average Monthly													
	12.9	15.4	18.1	13.8	19.4	18.2	16.9	17.6	16.9	17.0	14.1	13.8		

[a]Data was not available.

APPENDIX 14. The precipitation recordings at the federal weather station at Puebla, Mexico.

Year	Total Monthly Precipitation in mm												Total for Year	Average Annual
	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEPT.	OCT.	NOV.	DEC.		
1958	82.5	19.4	0.0	8.3	32.2	111.6	124.1	172.3	266.9	144.2	142.9	25.8	1130.2	94.2
1959	10.2	0.0	74.2	0.0	58.6	250.9	133.1	233.7	61.6	124.5	0.5	0.0	947.3	78.9
1960	4.1	---[a]	1.0	15.5	35.3	86.4	207.5	162.2	182.2	86.9	9.3	1.5	791.9	66.0
1961	----	----	7.9	13.4	33.9	-----	147.0	71.9	156.0	54.8	43.8	18.8	------	60.8
1962	0.0	0.0	----	55.4	90.5	121.6	55.4	107.3	108.7	92.5	38.4	9.9	679.7	56.6
1963	0.0	0.0	8.0	7.0	76.3	133.6	203.0	191.0	95.2	117.6	10.6	0.0	842.3	70.2
1964	----	0.0	----	----	138.8	203.7	-----	163.1	214.2	-----	-----	----	------	----
	Average Monthly													
	19.4	3.5	18.2	16.6	66.5	151.3	145.0	157.4	155.0	103.4	40.9	9.3		

[a]Data was not available.

APPENDIX 15. The average relative abundance of Dendroctonus frontalis and Ips sp. from samples of bark on untreated check logs about the time of the insecticidal applications. Note trial periods in Appendix 17.

Lab. Trial	Adults		Pupae		Larvae			Ave. No. of Insects per	
	Dead	Live	Dead	Live	Dead	Live	Eggs	10 cm belt	Barrel
				Dendroctonus frontalis					
1	8	13	0	11	0	175	0	207	5278
2	4	18	0	0	2	101	49	174	4437
3	0	10	0	1	0	82	31	124	3162
4	4	4	0	0	1	47	0	56	1423
5	0	7	0	0	0	37	0	44	1122
6	0	35	1	33	1	93	1	164	4182
				Ips sp.					
3	0	16	0	0	0	20	1	37	943
4	1	3	0	0	0	17	0	21	535
5	0	6	0	1	0	26	0	33	841

APPENDIX 16. The average number of adult Dendroctonus frontalis, Ips sp., parasites, and Clerid predators to emerge from four barrels of untreated check logs in the laboratory trials. Note trial periods in Appendix 17.

Lab. Trials	D. frontalis	Ips sp.	Parasites	Predators	Total
1	1028	0	16	5[a]	1049
2	2267	22	10[a]	5[a]	2304
3	1338	410	52	24	1824
4	890	946	669	29	2534
5	1020	126	65	18	1229
6	1748	0	1021	36	2805

[a]Estimate.

APPENDIX 17. The dates of manufacture of the commercial insecticide formulations and the laboratory experimental trial periods. Also included are the per cent of the active ingredients. All dilutions were mixed on a weight basis.

Lab. Trial	Lab. Trial Periods	Dates of Manufacture			
		BHC	Malathion	EDB	Carbaryl
1	Mar-Jun '63	Nov. '60[a] (10%)	1960 (50%)	Mar. '61 (85%)	Nov. '60 (85%)
2	Jul-Nov '63	Jul. '63 (5%)	Jun. '63 (50%)	1960 (85%)	Jul. '63 (85%)
3	Nov-Feb '64	Jul. '63 (5%)	Jun. '63 (50%)	1960 (85%)	Jul. '63 (85%)
4	Feb-May '64	Jul. '63 (5%)	Jun. '63 (50%)	1960 (85%)	Jul. '63 (85%)
5	May-Sep '64	Jul. '63 (5%)	Apr. '64 (50%)	1960 (85%)	Jul. '63 (85%)
6	Oct-Mar '65	Jul. '63 (5%)	Apr. '64 (50%)	1960 (85%)	Jul. '63 (85%)
Field Trial	Jan-May '64	Jul. '63 (5%)	Jun. '63 (50%)	1960 (85%)	Jul. '63 (85%)

[a]gamma isomer content.

APPENDIX 18. The average per cent mortality and the number of Dendroctonus frontalis adults which emerged in the Laboratory Trials from logs treated with BHC.

Lab. Trials	Per Cent Active Ingredient[a] 0.012	0.025	0.05	0.10	0.125	0.25	0.50	0.75	1.00	1.50	Check Ave.
					Per Cent Mortality						
1						71.4	80.3	81.8	86.6		
2							99.3		99.2	93.2	
3					99.3	99.1	99.7	99.5			
4			99.9	97.8	99.7	99.9					
5		95.0	98.3	98.9	98.6						
6	79.3	91.0	95.5	99.8							
Ave. 2-6	79.3	93.0	97.9	98.8	99.2	99.5	99.5	99.5	99.2	93.2	
					Number Emerged						
1						294	203	188	138		1028
2							20		6	30	2267
3					10	12	6	8			1338
4			8	19	2	8					890
5		51	17	11	14						1020
6	361	157	78	4							1748
Ave. 2-6	361	104	34	11	9	10	9	8	6	30	1452

[a]gamma isomer content.

APPENDIX 19. The average per cent mortality and the number of Dendroctonus frontalis adults which emerged in the Laboratory Trials from logs treated with malathion.

Lab. Trials	Per Cent Active Ingredient 0.125	0.25	0.50	0.75	1.00	1.50	Check Ave.
			Per Cent Mortality				
1		57.8	15.2	1.2	27.4		
2			96.1		99.2	99.2	
3	82.9	91.1	94.4	98.8			
4	84.5	86.9	94.8	97.7			
5	71.7	92.0	98.2	98.6			
6	89.5	97.8	99.2	95.8			
Ave. 2-6	82.2	92.0	96.5	97.7	99.2	99.2	
			Number Emerged				
1		434	873	1017	747		1028
2			80		6	7	2267
3	232	110	76	26			1338
4	137	116	45	26			890
5	289	82	18	14			1020
6	184	39	14	73			1748
Ave. 2-6	210	86	46	34	6	7	1452

APPENDIX 20. The average per cent mortality and the number of Dendroctonus frontalis adults which emerged in the Laboratory Trials from logs treated with EDB.

Lab. Trials	Per Cent Active Ingredient												Check Ave.
	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	
					Per Cent Mortality								
1	66.4	21.5	12.4	38.4									
2		0.0		29.1		96.8							
3					83.5	80.6	98.9	94.1					
4							92.1	90.7	92.2	97.4			
5								99.8	99.4	67.5	95.3		
6									94.6	99.1	99.0	98.4	
Ave. 2-6		0.0		29.1	83.5	88.7	95.5	94.9	95.4	88.0	97.2	98.4	
					Number Emerged								
1	346	808	902	634									1028
2		3154		1597		83							2267
3					227	262	18	68					1338
4							70	82	69	23			890
5								5	6	331	48		1020
6									94	16	17	28	1748
Ave. 2-6		3154		1597	227	172	44	51	56	123	32	28	1452

APPENDIX 21. The average per cent mortality and the number of Dendroctonus frontalis adults which emerged in the Laboratory Trials from logs treated with Carbaryl.

Lab. Trials	Per Cent Active Ingredient 0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	Check Ave.
					Per Cent Mortality								
1	5.6	51.8	29.2	53.6									
2		59.1		63.2		78.1							
3					58.2	64.7	86.2	94.6					
4							98.7	98.8	98.4	92.7			
5								97.4	98.4	98.7	97.9		
6									95.7	96.5	98.0	99.7	
Ave. 2-6		59.1		63.2	58.2	71.4	92.5	96.9	97.5	96.0	98.0	99.7	
					Number Emerged								
1	972	496	729	483									1028
2		918		820		486							2267
3					560	475	185	74					1338
4							11	10	14	64			890
5								27	16	13	21		1020
6									76	62	37	6	1748
Ave. 2-6		918		820	560	480	98	37	35	46	29	6	1452

APPENDIX 22. The average per cent mortality and the number of Ips sp. adults which emerged in the laboratory trials from logs treated with BHC.

Lab. Trials	Per Cent Active Ingredient[a] 0.025	0.05	0.10	0.125	0.25	0.50	0.75	Check Ave.
				Per Cent Mortality				
3				100.0	99.1	100.0	100.0	
4		99.8	98.5	99.3	99.7			
5	96.8	96.8	98.4	97.6				
Ave.	96.8	98.3	98.4	99.0	99.4	100.0	100.0	
				Number Emerged				
3				0	3	0	0	410
4		1	14	6	2			946
5	4	4	2	3				126
Ave.	4	2	8	3	2	0	0	494

[a]gamma isomer content.

APPENDIX 23. The average per cent mortality and the number of Ips sp. adults which emerged in the laboratory trials from logs treated with malathion.

Lab. Trials	Per Cent Active Ingredient 0.125	0.25	0.50	0.75	Check Ave.
			Per Cent Mortality		
3	99.1	98.3	99.3	100.0	
4	97.2	97.6	91.2	98.1	
5	65.9	92.9	92.9	98.4	
Ave.	87.4	96.3	94.5	98.8	
			Number Emerged		
3	3	5	1	0	410
4	26	22	83	17	946
5	43	9	9	2	126
Ave.	24	12	31	6	494

APPENDIX 24. The average per cent mortality and the number of Ips sp. adults which emerged in the laboratory trials from logs treated with EDB.

Lab. Trials	Per Cent Active Ingredient 1.25	1.50	1.75	2.00	2.25	2.50	2.75	Check Ave.
				Per Cent Mortality				
3	99.2	96.2	99.2	99.2				
4			99.1	92.9	98.5	98.7		
5				100.0	100.0	97.6	99.2	
Ave.	99.2	96.2	99.2	97.4	99.3	98.2	99.2	
				Number Emerged				
3	2	14	2	2				410
4			8	67	14	12		946
5				0	0	3	1	126
Ave.	2	14	5	23	7	7	1	494

APPENDIX 25. The average per cent mortality and the number of *Ips* sp. adults which emerged in the laboratory trials from logs treated with Carbaryl.

Lab. Trials	Per Cent Active Ingredient 1.25	1.50	1.75	2.00	2.25	2.50	2.75	Check Ave.
				Per Cent Mortality				
3	96.3	98.2	99.1	99.2				
4			96.5	99.4	93.7	97.1		
5				95.2	98.4	100.0	99.2	
Ave.	96.3	98.2	97.8	97.9	96.1	98.6	99.2	
				Number Emerged				
3	13	6	3	2				410
4			35	5	59	27		946
5				6	2	0	1	126
Ave.	13	6	19	4	30	13	1	494

APPENDIX 26. The average per cent mortality and the number of adult parasites of D. frontalis and Ips sp. that emerged in the laboratory trials from logs treated with BHC.

Lab. Trials	Per Cent Active Ingredient[a] 0.012	0.025	0.05	0.10	0.125	0.25	0.50	0.75	Check Ave.
				Per Cent Mortality					
3					100.0	100.0	100.0	100.0	
4			99.4	99.2	99.2	100.0			
5		98.5	100.0	100.0	98.5				
6	95.6	100.0	99.9	99.7					
Ave.	95.6	99.3	99.8	99.6	99.2	100.0	100.0	100.0	
				Number Emerged					
3					0	0	0	0	52
4			3	5	5	0			669
5		1	0	0	1				65
6	148	0	1	3					1021
Ave.	148	0	1	3	2	0	0	0	451

[a]gamma isomer content.

APPENDIX 27. The average per cent mortality and the number of adult parasites of D. frontalis and Ips. sp. that emerged in the laboratory trials from logs treated with malathion.

Lab. Trials	Per Cent Active Ingredient 0.125	0.25	0.50	0.75	Check Ave.
			Per Cent Mortality		
3	73.4	86.4	100.0	98.4	
4	90.3	95.6	97.5	94.2	
5	98.2	95.4	100.0	100.0	
6	98.2	98.9	98.4	98.6	
Ave.	90.0	94.1	99.0	97.8	
3	14	9	0	1	52
4	64	27	15	38	669
5	7	3	0	0	65
6	12	11	16	14	1021
Ave.	24	12	6	13	451

APPENDIX 28. The average per cent mortality and the number of adult parasites of D. frontalis and Ips. sp. that emerged in the laboratory trials from logs treated with EDB.

Lab. Trials	Per Cent Active Ingredient 1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	Check Ave.
				Per Cent Mortality					
3	100.0	100.0	100.0	98.4					
4			99.7	98.3	100.0	100.0			
5				100.0	100.0	100.0	100.0		
6					95.3	98.9	99.1	98.3	
Ave.	100.0	100.0	99.9	98.9	98.4	99.6	99.6	98.3	
				Number Emerged					
3	0	0	0	1					52
4			6	10	0	0			669
5				0	0	0	0		65
6					48	11	9	17	1021
Ave.	0	0	3	4	16	4	4	17	451

APPENDIX 29. The average per cent mortality and the number of adult parasites of D. frontalis and Ips. sp. that emerged in the laboratory trials from logs treated with Carbaryl.

Lab. Trials	Per Cent Active Ingredient 1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	Check Ave.
				Per Cent Mortality					
3	94.1	94.1	92.2	98.4					
4			99.7	99.3	99.2	99.3			
5				100.0	100.0	98.5	98.5		
6					100.0	100.0	100.0	99.6	
Ave.	94.1	94.1	96.0	99.2	99.7	99.3	99.3	99.6	
				Number Emerged					
3	3	3	4	1					52
4			6	4	5	14			669
5				0	0	1	1		65
6					0	0	0	4	1021
Ave.	3	3	5	2	2	5	0	4	451

APPENDIX 30. The average per cent mortality and the number of adult Clerid predators of D. frontalis and Ips sp. that emerged in the laboratory trials from logs treated with BHC.

Lab. Trials	Per Cent Active Ingredient[a] 0.012	0.025	0.05	0.10	0.125	0.25	0.50	0.75	Check Ave.
					Per Cent Mortality				
3					100.0	100.0	100.0	100.0	
4			86.6	72.1	89.2	79.9			
5		100.0	100.0	100.0	100.0				
6	100.0	97.0	100.0	100.0					
Ave.	100.0	98.5	95.5	90.7	96.4	90.1	100.0	100.0	
					Number Emerged				
3					0	0	0	0	24
4			4	8	3	6			29
5		0	0	0	0				18
6	0	1	0	0					36
Ave.	0	0	1	3	1	3	0	0	27

[a]gamma isomer content.

APPENDIX 31. The average per cent mortality and the number of adult Clerid predators of D. frontalis and Ips sp. that emerged in the laboratory trials from logs treated with malathion.

Lab. Trials	Per Cent Active Ingredient 0.125	0.25	0.50	0.75	Check Ave.
		Per Cent Mortality			
3	91.2	100.0	100.0	100.0	
4	82.2	100.0	93.3	79.9	
5	83.3	94.4	100.0	100.0	
6	97.0	100.0	100.0	100.0	
Ave.	88.4	98.6	98.3	95.0	
		Number Emerged			
3	2	0	0	0	24
4	5	0	2	6	29
5	3	1	0	0	18
6	1	0	0	0	36
Ave.	3	0	0	1	27

APPENDIX 32. The average per cent mortality and the number of adult Clerid predators of D. frontalis and Ips sp. that emerged in the laboratory trials from logs treated with EDB.

Lab. Trials	Per Cent Active Ingredient 1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	Check Ave.
				Per Cent Mortality					
3	100.0	100.0	100.0	100.0					
4			89.2	100.0	100.0	51.2			
5				100.0	100.0	100.0	100.0		
6					100.0	97.0	100.0	100.0	
				Number Emerged					
3	0	0	0	0					24
4			3	0	0	14			29
5				0	0	0	0		18
6					0	1	0	0	36
Ave.	0	0	1	0	0	5	0	0	27

APPENDIX 33. The average per cent mortality and the number of adult Clerid predators of D. frontalis and Ips sp. that emerged in the laboratory trials from logs treated with Carbaryl.

Lab. Trials	Per Cent Active Ingredient 1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	Check Ave.
				Per Cent Mortality					
3	91.2	87.1	100.0	100.0					
4			86.6	100.0	100.0	79.9			
5				100.0	100.0	100.0	94.4		
6					89.9	97.0	91.7	97.0	
Ave.	91.2	87.1	93.3	100.0	96.3	92.3	93.1	97.0	
				Number Emerged					
3	2	3	0	0					24
4			4	0	0	6			29
5				0	0	0	1		18
6					4	1	3	1	36
Ave.	2	3	2	0	1	2	2	1	27

APPENDIX 34. The results after 48 hours of BHC[a] and malathion topical application on D. frontalis. The data are presented as analysis of variance with per cent mortality data transformed to arc sin $\sqrt{\%}$.

Source	df	SS	MS	F
Analysis of Variance for Larvae				
Experiments	2	855.904	427.952	1.306
Insecticides	1	30.690	30.690	
Error (Exp. x Int.)	2	655.595	327.798	
Time	1	1335.841	1335.841	60.72**
I. Time x Insect.	1	4.997	4.997	
Error (Tim. x Int.)	4	88.000	22.000	
Concentrations	5	7913.227	1582.645	16.341**
I. Int. x Concent.	5	389.207	77.841	
I. Tim. x Concent.	5	161.194	32.239	
I. Int. x Tim. x Concent.	5	104.506	20.901	
Error (Concent. x I.)	40	3874.088	96.852	
Total	71	15413.249		
Analysis of Variance for Adult				
Experiments	3	1030.65	343.55	2.841
Insecticides	1	330.46	330.46	2.733
Error (Exp. x Int.)	3	362.72	120.91	
Time	1	6477.64	6477.64	119.206**
I. Time x Insect	6	356.36	356.36	6.557*
Error (Tim. x Int.)	5	326.09	54.34	
Concentrations	5	26941.57	5388.31	66.621**
I. Int. x Concent.)	5	1153.40	230.68	2.852*
I. Tim. x Concent.)	5	74.12	14.83	
I. Int. x Tim. x Concent.	5	189.09	37.82	
Error (Concent. x I.)	60	4852.54	80.88	
Total	95	42094.64		

[a]gamma isomer content.

APPENDIX 35. The number of emerged beetles of Dendroctonus frontalis based on exit holes counted from trees four months after being treated with insecticides with diesel oil in the field experiments.

Diesel Oil %	Per Cent Active Ingredient 0.50	1.00	1.50	2.50	4.00	Check	Check
			BHC[a]				
25	15	26	0	10		1076	806
25	0	5	5	0		826	1239
37.5	15	51	5	5		607	
37.5	153	10	0	0		1433	
50	26	20	0	0		1505	
50	31	0	0	---[b]		2800	
						1287 = Check Average	
			Malathion				
25	0	---	10	26		1663	
25	5	---	5	26		954	
37.5	66	41	0	122		566	
37.5	230	0	0	0		709	
50	46	15	26	0		776	
50	0	0	10	26		128	
						779 = Check Average	
			EDB				
25		816	---	117	---	394	372
25		---	---	51	26	168	785
37.5		---	---	168	194	179	
37.5		---	66	107	102	265	
50		495	---	---	0	515	
50		372	---	112	56	316	
						374 = Check Average	
			Carbaryl				
25		184	---	107	56	984	780
25		---	---	---	71	423	755
37.5		321	15	---	31	893	704
37.5		265	31	66	82	1673	617
50		918	---	82	260	1856	872
50		689	31	214	128	1765	959
						1023 = Check Average	

[a]gamma isomer content.
[b]data missing, see text.